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SPECTRAL STRUCTURES FOR ELEMENTS OF THE SECOND LONG PERIOD[1]

By W. F. Meggers and C. C. Kiess

I. INTRODUCTION

In a paper published[2] in 1924, regularities in the arc and spark spectra of the elements K-19 to Fe-26 were summarized and the displacement law of spectra was verified across the entire table. At that time it was stated that similar regularities were being sought for among the spectra of elements whose atomic numbers are 37 to 44 and that the preliminary results indicated the same spectroscopic laws to be valid for the second long period as for the first. These investigations have been extended during the past year and some of the details are being given in the present article. The analyses, although in some cases still incomplete, have been carried as far as the available data will permit, and rather than delay until further observations are made, it was considered that the main features of these spectra as now known are of such interest for the development of the theory of multiplet structures that publication is desirable.

The spectra dealt with are those of the elements rubidium, strontium, yttrium, zirconium, columbium, molybdenum, (eka manganese), ruthenium, rhodium, and palladium, most of the details being for the four elements following strontium, since our time was largely devoted to these, and new observational data were obtained for some of them. The laws of spectral structure have been summarized in the paper above referred to.

[1] Published by permission of the Director of the Bureau of Standards, U. S. Department of Commerce.

[2] Meggers, Kiess and Walters, Jr., J.O.S.A. & R.S.I., *9*, p.355; 1924.

During the past year the rules and theory of spectral structures have been advanced in no small measure. Mention may be made of (a) the extended selection rule[3] for azimuthal quantum numbers k, of (b) the quantitative rules governing intensites[4] of lines in multiplets, and of (c) the introduction of a quantum number[5] l to replace k in complex spectra which are emitted by atoms with several valence electrons. (a) The rule that isomorphous terms combine when $\Delta k = 0, \pm 2 \ldots\ldots$ and heteromorphous terms combine only when $\Delta k = 1, \pm 3 \ldots\ldots$ has now been verified in a considerable number of spectra. (b) Sommerfeld's qualitative intensity rule, first refined in a restricted manner by the sum rule of Burger and Dorgelo[6] has finally been extended to the exact computation of relative intensities of lines in multiplets. Unfortunately no quantitative measurements of intensities exist for spectral lines of the elements under discussion here and since multiplets in the spectra of the heavy elements usually cover rather wide ranges of wave lengths, relative intensity estimates are difficult and often in error so that it is impossible at present to test the theory in this direction. (c) Certain difficulties arising from the more or less arbitrary association of term types S, P, D, F, etc., with the azimuthal quantum numbers $k = 1, 2, 3, 4$, etc., of the last bound electron have almost entirely been removed by the adoption of a quantum number l defined in general as the quantized sum of the k values of all the individual electrons. In what follows, term types S, P, D, F, G, will be understood to correspond to the quantum numbers $l = 1, 2, 3, 4, 5$. Otherwise, the notation is that which was arrived at last year,[7] and which has since come into common use for the symbolical description of regularities in line spectra. When in the tables a wave length is preceded by an asterisk the line belongs to the class known as *raies ultimes*, the most sensitive lines for the purpose of practical spectrochemical analysis. In connection with the data given below, we have occasion to discuss the interval rule, and rules for Zeeman effects. In addition we extend the rule that *raies ultimes* are related to the normal state of the atom.

[3] Laporte, ZS f. Physik *23*, p. 166; 1924.
[4] Kronig, ZS f. Physik, *31*, p. 885; 1925, Ibid, *32*, p.261; 1925.
Sommerfeld and Hönl, Berliner Akad. Wiss., *9*, p. 141; 1925.
Russell, Proc. Nat. Acad. Sci., *11*, pp. 314, 322; 1925.
[5] Heisenberg, ZS f. Physik, *32*, p. 841; 1925.
Hund, ZS f. Physik, *33*, p.345; 1925.
[6] Burger and Dorgelo, ZS f. Physik, *31*, p. 355; 1925.
[7] Astroph. Journ., *61*, p. 60; 1925.

II. SPECTRAL STRUCTURES (Rb—37 TO Pd—46)

Rb I: The arc spectrum of rubidium like that of any other alkali metal is characterised by doublets which have been fully described in treatises on spectral series.[8]

Rb II: The spark spectrum of rubidium has been investigated by Reinheimer[9] who found regularities similar to those characterizing a rare gas spectrum. This is in qualitative agreement with the displacement law.

Sr I: Singlets and triplets have long been recognized in the arc spectra of alkaline earths. The well known series for strontium have been described elsewhere[8] but new terms were recently found by Russell and Saunders.[10]

Sr II: Doublets in the spark spectrum of strontium were discovered by Fowler in 1914. The series are presented in his 1922 Report.[8] Structural resemblances of the spark spectra of the akaline earths with the arc spectra of the alkalies constituted the first good evidence for the displacement law of spectra.

Y I: On entering Column III of the periodic table with any of the long periods one of the most noticeable features of the spectra is the transition from series character to so-called multiplet structures, that is, instead of extended sequences of similar terms, a large number of complex terms belonging to various overlapping sets are usually found with little or no possibility of their being expressible in series form. Doublets[11] and quartets[12] have already been indicated for the arc spectrum of yttrium but inter-system combinations have been found only recently. New data on Zeeman-effect were obtained through cooperation with the late Professor B. E. Moore, and Dr. King has kindly placed at our disposal his intensity estimates and temperature classification for yttrium lines. These data have made it possible to extend the doublet system and to find the combinations between doublet and quartet terms. The relative terms and intervals are given in Table 1.

Although no laboratory absorption data exist for the identification of the lowest term in *Y* I, the supposition that $^2D_2$ represents the normal state is supported by the temperature classification, by the enhancement

[8] Fowler, Series in Line Spectra, London, 1922.
Paschen-Götze, Seriengesetze der Linienspektren, Berlin, 1922.
Hicks, A Treatise on the Analysis of Spectra, Cambridge, 1922.

[9] Reinheimer, Ann. d. Phys., *71*, p. 162; 1923.

[10] Russell and Saunders, Astroph. Journ., *61*, p. 38; 1925.

[11] Meggers, Journ. Wash. Acad. Sci., *14*, p. 419; 1924.

[12] Meggers and Moore, Journ. Wash. Acad. Sci., *15*, p. 207; 1925.

TABLE 1. *Relative Terms in the Y I Spectrum*

Term Symbol	Term Value	Interval	Combinations
$^2D_3$	00.0	530.4	a^3P, b^3P, a^3D', b^3D', c^3D', a^3F, b^3F, c^3F, $^4D'$, ^4F, $^4G'$
$^2D_2$	530.4		
$^4F_2'$	10937.3	141.3	$^4D'$, ^4F, $^4G'$, c^3D', b^3F, c^3F
$^4F_3'$	11078.6	199.4	
$^4F_4'$	11278.0	254.1	
$^4F_5'$	11532.1		
a^3D_3'	16066.0	− 80.1	^2D
a^3D_2'	16146.1		
a^3F_3	21528.5	387.1	^2D
a^3F_4	21915.6		
b^3D_3'	24131.1	615.3	^2D
a^3P_2	24480.6	−218.1	^2D
b^3F_3	24518.5		^2D, $^4F'$
a^3P_1	24698.7	381.0	
b^3D_2'	24746.4		
b^3F_4	24899.5		
b^3P_1	27824.8	314.8	^2D
b^3P_2	28139.6		
$^4G_3'$	28694.0	294.7	^2D, $^4F'$
$^4G_4'$	28988.7	375.5	
$^4G_5'$	29364.2	456.2	
$^4G_6'$	29820.4		

TABLE 1—*Continued*

Term Symbol	Term Value	Interval	Combinations
$^4F_2$	31508.5		$^2D, {}^4F'$
		171.5	
$^4F_3$	31680.0		
		229.1	
$^4F_4$	31909.1		
		279.0	
$^4F_5$	32188.1		
$^4D_1'$	33215.3		$^2D, {}^4F'$
		50.1	
$^4D_2'$	33265.4		
		92.3	
$^4D_3'$	33357.7		
		256.8	
c^2F_3	33608.4		$^2D, {}^4F'$
$^4D_4'$	33614.5		
		421.3	
c^2D_2'	33906.9		$^2D, {}^4F'$
c^2F_4	34029.7	340.8	
c^2D_3'	34247.7		

in sun spots of lines involving this level, and by the fact that the *raie ultime* is $^2D_3-{}^2F_4$. It will be noted that two of the doublet terms, a ^2P and a $^2D'$, are inverted, but that no low-lying metastable terms have been detected. The lowest quartet term $^4F'$ is about 11,000 wave number units higher than the lowest doublet term ^2D; lines involving the former are temperature class III in the average while the majority of those involving the latter are class II according to King. This is in accord with the observation that, in general, lines assigned by King to adjacent temperature classes originate with spectral terms separated by approximately 10,000 units.

The prominent quartet-system multiplets have already been published, and it suffices to give details for the revised doublet system and for the inter-system combinations. These are found in Table 2.

Y II: According to the displacement law the spark spectrum of yttrium should contain singlets and triplets like the arc spectrum of strontium. Two multiplets of the type $^3D-{}^3P$ were recognized among

TABLE 2. *Multiplets in the Y I Spectrum*

	$^3D_3$	530.4	$^3D_2$
c^3D_3'	2964.96 (30, II)		2919.06 (20, II)
	33717.49		34247.63
340.8			
c^3D_2'	2995.25 (10, III)		2948.39 (30, II)
	33376.50		33906.92
c^3F_4	2984.26 (50, II)		
	33499.38		
421.3			
c^3F_3	3022.27 (12, II)		2974.58 (35, II)
	33078.09		33608.37
b^3P_2	3620.95 (400, II)		3552.70 (40, I)
	27609.21		28139.61
314.8			
b^3P_1			3592.90 (200, II)
			27824.78
b^3F_4	*4102.42 (350, II)		
	24369.03		
381.0			
b^3F_3	4167.57 (100, II)		*4077.39 (300, II)
	23988.06		24518.58
b^3D_3'	4128.35 (300, II)		4039.84 (60, II)
	24215.95		24746.47
615.3			
b^3D_2'	4235.94 (100, II)		4142.88 (200, II)
	23600.88		24131.04
a^3P_2	4174.18 (100, II)		4083.72 (100, II)
	23950.08		24480.58
−218.1			
a^3P_1			4047.66 (80, II)
			24698.68
a^3F_4	4674.85 (125, I)		
	21385.11		
387.1			
a^3F_3	4761.02 (40, I)		4643.68 (150, I)
	20998.04		21528.62
a^3D_3'	6435.030 (500, I)		6222.585 (250, IA)
	15535.66		16066.05
−80.1			
a^3D_2'	6402.025 (200, IA)		6191.726 (500, IA)
	15615.75		16146.13

TABLE 2—*Continued*

		$^3D_3$	530.4		$^3D_2$		
$^4D_4'$		3021.70 (15, II)					
		33084.32					
256.8							
$^4D_3'$		3045.36 (20, II)			2996.93 (20, III)		
		32827.36			33357.80		
92.3							
$^4D_2'$		..... ?			3005.24 (12, III)		
		32735.1			33265.58		
50.1							
$^4D_1'$					..... ?		
					33215.4		
$^4F_5$							
279.0							
$^4F_4$		3185.93 (2, IIIA)					
		31378.95					
229.1							
$^4F_3$		3209.38 (1)			3155.62 (3, IIIA)		
		31149.74			31680.36		
171.6							
$^4F_2$		..... ?			3172.85 (4, III A)		
		30978.1			31508.37		
$^4G_6'$							
456.2							
$^4G_5'$							
375.5							
$^4G_4'$		3512.88 (20, III)					
		28458.57					
294.7							
$^4G_3'$		..... ?			3484.05 (10, III)		
		28163.9			28694.07		
	$^4F_5'$	254.1	$^4F_4'$	199.4	$^4F_3'$	141.3	$^4F_2'$
c^3D_3'			4352.34 (5, III)		4314.92 (1)		
			22969.71		23168.90		
340.8							
c^3D_2'					4379.33 (6, III)	4352.34 (5 III)*d*?	
					22828.13	22969.71	
c^3F_4	4443.66 (15, III)		4394.03 (3, III)		..... ?		
	22497.69		22751.79		*22951.1*		
421.3							
c^3F_3			4476.92 (25, III)		4437.32 (10, III)	4409.71 (1)	
			22330.55		22529.83	22670.91	

the spark lines of yttrium by Popow[13] in 1914. These and six additional groups of the triplet system have already been published.[11] Among the latter were two involving a peculiar $^3P'$ term ($^3P_0'$ and $^3P_2'$ coincident)

TABLE 3. *Relative terms in the Y II Spectrum*

Term Symbol	Term value	Interval	Combination
$^3D_1$	00.0		$a^3P, {}^3F, {}^3D', b^3P, {}^1P, {}^1D', {}^1F$
		204.9	
$^3D_2$	204.9		
		404.8	
$^3D_3$	609.7		
a^1D_2	2456.4		$a^3P, {}^3F, {}^3D', b^3P, {}^1D', {}^1F$
$^3F_2'$	7163.1		$^3F, {}^3D', {}^1P, {}^1D'$
		324.9	
$^3F_3'$	7488.0		
		415.4	
$^3F_4'$	7903.4		
$^3P_0'$	13043.3		$^3D', b^3P, {}^1F$
		135.1	
$^3P_1'$	13178.4		
		79.8	
$^3P_2'$	13258.2		
b^1D_2	13992.7		$^3D', b\,{}^3P, {}^1P, {}^1F$
a^3P_0	22604.8		$^3D, {}^3P', a\,{}^1D, b\,{}^3P$
		331.3	
a^3P_1	22936.0		
		870.9	
a^3P_2	23806.9		
$^1D_2'$	25307.1		$^3D, {}^3F', a\,{}^1D$
$^3F_2$	26387.0		$^3D, {}^3F', a\,{}^1D$
		305.4	
$^1P_1$	26676.6		$^3D, {}^3F', {}^3P', b\,{}^1D$
$^3F_3$	26692.4		
		861.6	
$^3F_4$	27554.0		
$^3D_1'$	27755.3		$^3D, {}^3F', {}^3P', a\,{}^1D, b\,{}^1D$
		134.7	
$^3D_2'$	27890.0		
		484.0	
$^3D_3'$	28374.0		
b^3P_0	31208.5		$^3D, {}^3P', a\,{}^1D, b\,{}^1D$
		75.3	
b^3P_1	31283.8		
		159.5	
b^3P_2	31443.3		
$^1F_3$	32496.8		$^3D, {}^3P', a\,{}^1D, b\,{}^1D$

[13] Popow, Ann. d. Phys., *45*, p. 163; 1914.

which was regarded as more or less doubtful. This term, however, has been corrected by means of another combination which was formerly over-looked, and by some combinations between the triplet system and the singlet terms which have been found more recently. The relative terms together with their combination relations are presented in Table 3. Although the level $^3D_1$ is certainly the lowest in the energy diagram of *Y* II, it is to be noted especially that several relatively low metastable states exist, and that the low $^1D_2$ term is only 2456.4 units above $^3D_1$. For some unknown reason the combinations $a^1D_2-{}^1P_1$, $^3D_2-{}^1D_2'$ and $a^1D_2-{}^3D_2'$ appear to be excluded.

With the exception of two lines, viz., 3496.07, 150 III E, and 3633.13, 200 III E, which are believed to involve singlet terms, the above combinations account for all the strong lines which have been observed in the yttrium spark.

In Table 4 only one additional triplet-system multiplet is given, followed by the singlet system and then by the inter-system combinations.

TABLE 4. *Multiplets in the Y* II *Spectrum*

	$^3P_2'$	79.8	$^3P_1'$	135.1	$^3P_0'$
b^3P_2	5497.39 (25, VE)		5473.36 (10, VE)		
	18185.43		18265.24		
159.5					
b^3P_1	5546.03 (3, VE)		5521.61 (30, II & E)		5480.71 (8, VE)
	18025.91		18105.64		18240.75
75.3					
b^3P_0			5544.58 (25, III & E)		
			18030.62		

$a^1D_2-{}^1F_3$	3327.88 (150, IIIE)	
	30040.59	
$a^1D-{}^1P_1$	..... ?	
	24220.2	
$a^1D_2-{}^1D_2'$	4374.95 (300, IIIE)	
	22851.04	
$b^1D_2-{}^1F_3$	5402.77 (20, VE)	
	18503.88	
$b^1D_2-{}^1P_1$	7881.90 (5, E)	
	12683.82	

	a^3P_2	870.9	a^3P_1	331.3	a^3P_0
a^1D_2	4682.31 (20, VE)		4881.45 (10 -)		
	21351.01		20480.01		

TABLE 4—*Continued*

	$^3F_4$	861.6	$^3F_3$	305.4	$^3F_2$
a^1D_2			4124.95 (20, IIIE)		4177.58 (125 IIIE)
			24235.90		23930.60
	$^3D_3'$	484.0	$^3D_2'$	134.7	$^3D_1'$
a^1D_2	..... ?		3930.66 (10, VE)		3951.61 (8 VE)
	25917.6		25433.84		25299.03
	b^3P_2	159.5	b^3P_1	75.3	b^3P_0
a^1D_2	3448.85 (35, VE)		3467.98 (20, VE)		
	28986.94		28827.00		
	$^3D_3$	404.8	$^3D_2$	204.9	$^3D_1$
$^1P_1$			3776.57 (40, IIIE)		3747.55 (20, IIIE)
			26471.55		26676.56
$^1D_2'$	..... ?		3982.64 (100, IIIE)		3950.37 (150, IIIE)
	24697.4		25101.91		25306.98
$^1F_3$	3135.17 (25, VE)		3095.88 (25, VE)		
	31886.94		32291.61		
	$^3F_4'$	415.4	$^3F_3'$	324.9	$^3F_2'$
$^1D_2'$			5610.36 (1 -)		5509.88 (40, VE)
			17819.25		18144.18
$^1F_3$	4065.04 (2 -)		..... ?		3946.22 (2 -)
	24593.11		*25008.6*		25333.58
$^1P_1$					5123.21 (40, VE)
					19513.61
	$^3P_2'$	79.8	$^3P_1'$	135.1	$^3P_0'$
$^1P_1$	7450.35 (5 -)		7406.23 (2 -)		7332.96 (2 -)
	13418.50		13498.42		13633.31
$^1F_3$	5196.44 (2, VE)				
	19238.62				
	$^3D_3'$	484.0	$^3D_2'$	134.7	$^3D_1'$
b^1D_2	6951.69 (3 -)		7193.74 (1 -)		7264.14 (7 -)
	14381.04		13897.15		13762.46
	b^3P_2	159.5	b^3P_1	75.3	b^3P_0
b^1D_2	5728.90 (3, VE)		5781.68 (2, VE)		
	17450.54		17291.23		

Zr I: The element zirconium occurs in the fourth column of the periodic system. Like Ti[14] its arc spectrum is made up of series regularities of odd multiplicity, while structures of even multiplicity characterize its spark spectrum. Most of the principal features of the arc and spark spectra have now been detected. Although the spectral structures of Zr, in general, parallel those of Ti, yet there are differences between the two, which will be discussed later when the completed details of the analysis are published. In the furtherance of our work on the Zr spectra, we have been aided by new wave length measurements, new observations on the Zeeman effect, and preliminary observations on the furnace spectra. The wave length measurements have been made in our own laboratory and have included the regions from 2100 to 9300A for the arc spectrum, and from 2060 to 4927A for the spark spectrum. The new Zeeman effects were observed by Prof. B. E. Moore as part of the cooperative program mentioned above. The measurements and reductions were made at the Bureau of Standards. These have verified most and corrected a few of Moore's[15] earlier observations and have furnished new data for the green, yellow and red lines up to 7200A. To Dr. King we are indebted for copies of his preliminary photographs of the furnace spectra. These proved of considerable help in the initial work of analyzing the spectrum.

Table 5 contains multiplets chosen from the triplet and quintet systems of the arc spectrum. As has already been stated[16] the lowest term of the arc spectrum is a three-fold F term. In the quintet system the lowest term is a five-fold F term which lies 5300 wave number units above the ^3F term. The multiplets which follow are combinations between D, F', and G terms with these low-lying F terms.

TABLE 5. *Multiplets in the Zr* I *spectrum.*

	$^3F_2$ 570.45	$^3F_3$ 670.40	$^3F_4$
$^3D_3$	..... ?	3766.72	3864.33 (5)
	27111.21	26540.76	25870.41
553.90			
$^3D_2$	3764.38 (6)	3847.01 (5)	
	26557.25	25986.85	
403.06			
$^3D_1$	3822.40 (6)		
	26154.19		

[14] Kiess and Kiess, J.O.S.A. & R.S.I., *8*, p. 607; 1924. Russell, Astroph. Journ., *61*, p. 223; 1925.
[15] Moore, Astroph. Journ., *28*, p. 8; 1908.
[16] Kiess and Kiess, Pop. Astron., *33*, p. 255; 1925.

TABLE 5—*Continued*

	$^3F_2$ 570.45	$^3F_3$ 670.40	$^3F_4$
$^3F_4'$		3791.40 (3)	3890.32 (7)
		26368.04	25697.56
494.52			
$^3F_3'$	3780.53 (6)	3863.87 (7)	3966.65 (6)
	26443.83	25873.49	25203.07
382.17			
$^3F_2'$	3835.96 (7)	3921.81 (6)	
	26061.76	25491.22	
$^3G_5$			* 3601.18 (8)
			27760.81
251.78			
$^3G_4$		* 3547.69 (8)	3634.14 (6)
		28179.33	27509.03
345.54			
$^3G_3$	* 3519.60 (8)	3591.72 (5)	3680.39 (3)
	28404.25	27833.91	27163.36
$^5D_4$		3353.15 (1)	3430.29 (3)
		29814.17	29143.72
297.17			
$^5D_3$	..... ?	3386.90 (1)	3465.63 (4)
	30087.5	29517.07	28846.54
239.77			
$^5D_2$	..... ?	3414.64 (5)	
	29847.5	29277.19	
170.36			
$^5D_1$	3368.64 (3)		
	29677.11		

	$^5F_1$ 152.86	$^5F_2$ 225.66	$^5F_3$ 291.46	$^5F_4$ 448.43	$^5F_5$
$^5D_4$			3977.33 (2)	4024.00 (5)	4081.24 (8)
			25135.42	24843.92	24495.45
297.17					
$^5D_3$		3988.69 (3)	4024.93 (5)	4072.71 (8)	
		25063.85	24838.18	24546.75	
239.77					
$^5D_2$	4002.56 (3)	4027.21 (6)	4064.17 (7)		
	24976.96	24824.12	24598.37		
170.36					
$^5D_1$	4030.04 (5)	4055.04 (6)			
	24806.63	24653.74			
89.09					
$^5D_0$	4044.57 (5)				
	24717.54				

TABLE 5—*Continued*

	$^5F_1$ 152.86	$^5F_2$ 225.66	$^5F_3$ 291.46	$^5F_4$ 448.43	$^5F_5$
$^5F_5'$				4166.37 (5)	4227.79 (8)
				23994.97	23646.36
412.78					
$^5F_4'$			4187.56 (6)	4239.32 (6)	4302.88 (8)
			23873.59	23582.06	23233.71
304.55					
$^5F_3'$		4201.46 (5)	4241.68 (5)	4294.78 (8)	
		23794.57	23568.96	23277.58	
222.98					
$^5F_2'$	4213.87 (5)	4241.20 (5)	4282.20 (6)		
	23724.51	23571.62	23345.94		
148.15					
$^5F_1'$	4240.36 (5)	4268.01 (8)			
	23576.28	23423.54			
$^4G_5$					4687.81 (8)
					21325.96
449.26					
$^4G_4$				4710.08 (8)	4788.70 (7)
				21225.16	20876.70
423.06					
$^4G_3$			4739.49 (8)	4805.89 (7)	4887.72 (1)
			21093.45	20802.00	20453.74
370.82					
$^4G_2$		4772.33 (8)	4824.30 (7)	4893.12 (5)	
		20948.29	20722.64	20431.18	
341.24					
$^4G_1$	4815.62 (7)	4851.36 (6)	4905.07 (5)		
	20759.98	20607.04	20381.41		

Zr II: In the spark spectrum of Zr the lowest term is an F term of the quartet system. In the doublet system the lowest term is $^2D'$ which lies 4300 cm^{-1} units above ^4F. The low doublet F term lies approximately 2000 wave number units above $^2D'$. Table 6 contains typical multiplets selected from each system.

TABLE 6. *Multiplets in the Zr* II *Spectrum*

	$^4F_2$ 314.69	$^4F_3$ 448.74	$^4F_4$ 559.37	$^4F_5$
$^4D_4$		3068.02 (2)	3110.87 (6)	3165.98 (7)
		32584.87	32136.06	31576.69
284.70				
$^4D_3$	3065.20 (2)	3095.07 (6)	3138.67 (7)	
	32614.85	32300.10	31851.43	
358.00				
$^4D_2$	3099.22 (6)	3129.76 (6)		
	32256.85	31942.10		
275.51				
$^4D_1$	3125.92 (6)			
	31981.34			

TABLE 6—*Continued*

	$^4F_2$ 314.69	$^4F_3$ 448.74	$^4F_4$ 559.37	$^4F_5$
$^4F_5'$			3214.19 (6)	3273.04 (8)
			31103.08	30543.86
617.15				
$^4F_4'$		3231.69 (6)	3279.25 (7)	3340.55 (6)
		30934.66	30486.02	29926.61
697.78				
$^4F_3'$	3272.21 (5)	3306.27 (7)	3356.07 (7)	
	30551.61	30236.89	29788.23	
773.88				
$^4F_2'$	3357.25 (6)	3393.12 (5)		
	29777.76	29462.97		
$^4G_5$				* 3391.95 (8)
				29473.14
956.05				
$^4G_4$			* 3438.22 (8)	3505.67 (5)
			29076.51	28517.09
930.88				
$^4G_3$		* 3496.18 (8)	3551.94 (6)	3623.97 (1)
		28594.50	28145.62	27586.21
925.10				
$^4G_2$	* 3572.48 (8)	3613.08 (6)	3672.65 (3)	
	27983.80	27669.35	27220.58	

	$^3D'_2$ 257.21	$^3D'_3$
$^3P'_2$	3157.00(5)	3182.86(7)
	31666.50	31409.23
−281.63		
$^3P'_1$	3129.17(6)	
	31948.13	
$^3D_3$	3714.77(6)	3750.64(5)
	26911.94	26654.57
724.63		
$^3D_2$	3817.59(6)	3855.43(3)
	26187.13	25930.12
$^3F'_4$		3836.76(9)
		26056.29
1056.96		
$^3F'_3$	3958.24(9)	3998.98(8)
	25256.63	24999.33
$^4G_4$		4096.63(4)
		24403.44
925.10		
$^4G_3$	4211.88(6)	4258.05(6)
	23735.70	23478.34

Cb I: The arc spectrum of columbium is expected to possess even multiplicities (2, 4 and 6) like that of vanadium. Some combinations of sextet terms were published[17] in 1924. These are the most conspicuous groups in the spectrum; they include the *raie ultime* ($^6D-{}^6F$) and indicate that the lowest energy level is $^6D_1$. On account of the lack of temperature classification for columbium lines, and insufficient Zeeman-effect data, it is difficult to analyse the quartet and doublet systems.

Two additional multiplets of the sextet system are given in Table 7. The spectrum of this element is being remeasured, and further details of its structure will be given later in connection with other data.

TABLE 7. *Multiplets in the Cb* I *Spectrum.*

	$^6D_4$ 355.0	$^6D_4$ 303.4	$^6D_3$ 237.8	$^6D_2$ 154.1	$^6D_1$
b^4P_4	3580.27 (15)	3535.28 (10)	3497.77(3)		
	27922.9	28278.2	28581.5		
320.8					
b^4P_3		3575.85 (10)	3537.50 (10)	3507.93 (4)	
		27957.4	28260.5	28498.7	
374.4					
b^4P_2			3584.95 (4)	3554.59 (15d)	3535.28 (10d?)
			27886.4	28124.6	28278.2
b^4D_4	3554.59 (15d)	3510.25 (3)			
	28124.6	28479.9			
625.6					
b^4D_4	3635.44 (2)	3589.08 (5)	3550.43 (5)		
	27499.2	27854.4	28157.6		
104.0					
b^4D_3		3602.55 (6)	3563.56 (15d)	3533.64 (3)	
		27750.2	28053.9	28291.3	
237.3					
b^4D_2			3593.95 (6)	3563.56 (15d)	2544.00 (8)
			27816.6	28053.9	28208.6
201.7					
b^4D_1?				3589.34 (5)	3569.45 (3)
				27852.4	28007.6

Cb II. The spectrum of ionized vanadium[18] having been found to originate largely with combinations of terms in triplet and quintet systems, similar spectral regularities were expected from the spark spectrum of columbium. With the aid of a few Zeeman-effect patterns observed by Jack[19] it has been relatively easy to detect what are perhaps the most important multiplets of CbII. As in the case of VII, a low ^5F term of CbII is involved in the production of the strongest spark lines,

[17] Meggers, Journ. Wash. Acad. Sci., *14*, p. 442; 1924.
[18] Meggers, ZS. f. Physik, *33*, p. 509; 1925.
[19] Jack, Proc. Roy. Irish Acad. Dublin, *30A*, p. 42: 1912.

those which are also present with great intensity in the ordinary arc. On account of the combination possibilities ($\Delta l = +1, 0, -1$), when a low lying term is identified in any complex spectrum it is the usual experience to find three multiplets in the same general portion of the spectrum. This is true also for Cb II. In Table 8 the combinations $^5F - {}^5D$, $^5F - {}^5F'$ and $^5F - {}^5G$ are given. The interval ratios are in fair agreement with the theoretical values only for terms ^5F and ^5G. In the same manner as for V II, the last interval of the ^5D term is abnormally small and the ^5F intervals are irregular.

Notwithstanding the prominence of these combinations the lowest energy level for Cb II is found to be a $^5D_0'$ level which lies 2357 cm^{-1} below $^5F_1$. The last two multiplets in Table 8 are combinations of this $^5D'$ term with the higher ^5D and $^5F'$ terms. The analogous $^5D'$ term in V II has not yet been identified, it probably lies considerably above ^5F in the energy diagram. If the custom of representing the lowest energy of a spectrum by an unprimed term were followed the primed terms of Cb II given here should be unprimed and *vice versa* but since this distinction is quite artificial these terms may retain the same designation as their V II analogues.

TABLE 8. *Multiplets in the Cb* II *Spectrum*

	$^5F_4$	603.6	$^5F_3$	512.9	$^5F_2$	401.0	$^5F_1$	272.3	$^5F_0$
$^5D_4$	2927.83 (10)		2876.98 (6)		2835.14 (2)				
	34145.1		34748.5		35261.3				
		75.0							
$^5D_3$			2883.21 (6)		2841.18 (3)		2809.15 (1)		
			34673.5		35186.4		35587.4		
		418.8							
$^5D_2$					2875.39 (6)		2842.67 (3)		2820.83 (1)
					34767.7		35167.9		35440.1
		316.8							
$^5D_1$							2868.52 (4)		2846.27 (3)
							34851.0		35123.5
		182.2							
$^5D_0$									2861.22 (3)
									34941.2
$^5F_5'$	2950.92 (10)		2899.24 (5)						
	33877.9		34481.7						
		495.7							
$^5F_4'$	2994.71 (6)		2941.56 (8)		2897.82 (5)				
	33382.5		33985.6		34498.6				
		151.7							
$^5F_3'$			2954.7 (1)		2910.62 (6)		2876.98 (6?)		
			33834.5		34346.9		34748.5		
		414.0							
$^5F_2'$					2946.13 (2)		2911.77 (4)		2888.82 (3)
					33932.9		34333.4		34606.1
		231.2							
$^5F_1'$							2931.48 (2)		2908.26 (5)
							34102.5		34374.8

TABLE 8—*Continued*

	$^5F_5$	603.6	$^5F_4$	512.9	$^5F_3$	401.0	$^5F_2$	272.3	$^5F_1$
$^4G_5$	* 3094.20 (15)								
	32309.1								
980.8									
$^4G_4$	3191.08 (4)		* 3130.79 (12)						
	31328.3		31931.6						
842.3									
$^4G_3$	3279.29 (1)		3215.57 (6)		*3163.37 (10)				
	30485.7		31089.7		31602.8				
713.1									
$^4G_2$			3291.04 (2)		3236.43 (10)		*3194.95 (10)		
			30376.8		30889.4		31290.4		
568.0									
$^4G_1$					3297.09 (1)		3254.01 (6)		*3225.43 (10)
					30321.1		30722.4		30994.7

	$^5D'_4$	423.6	$^5D'_3$	362.8	$^5D'_2$	279.6	$^5D'_1$	159.0	$^5D'_0$
$^5D_4$	2697.04 (8)		2666.57 (3)						
	37066.7		37490.2						
75.0									
$^5D_3$	3702.50 (3)		2671.91 (5)		2646.25 (4)				
	36991.8		37415.4		37778.1				
418.8									
$^5D_2$			2702.18 (3)		2675.93 (3)		2656.04 (3)		
			36996.2		37359.2		37638.8		
316.8									
$^5D_1$					2698.85 (3)		2678.64 (2)		2667.27 (2)
					37041.8		37321.4		37480.4
182.2									
$^5D_0$							2691.75 (2)		
							37139.5		

$^5F'_5$	2716.59 (4)								
	36800.0								
495.7									
$^5F'_4$	2753.71 (1)		2721.97 (5)						
	36303.9		36727.3						
151.7									
$^5F'_3$	2765.27 (2)		3733.22 (2)		2706.39 (3)				
	36152.1		36576.0		36938.6				
414.0									
$^5F'_2$			2764.56 (2)		2737.05 (3)		2716.27 (2)		
			36161.5		36524.8		36804.3		
231.2									
$^5F'_1$					2754.54 (2)		2733.45 (1)		2721.63 (2)
					36293.0		36573.0		36731.8

Mo I: The structure of the arc spectrum of Mo has been investigated by Kiess[20] and by Catalan.[21] In general, it resembles that of Cr which precedes it in the sixth column of the periodic table. The lowest term is an S term of the septet system. Above it come in order an S term and a five-fold D term of the quintet system. The transitions between higher terms of the quintet system and this low ^5D term account for all the multiplets which have so far been published. The classification of the lines in the Mo arc spectrum is being continued at the Bureau of Standards, and from the many new multiplets which have been found those presented in Table 9 have been selected to show the existence in the quintet system of low metastable P' and G terms. The $^5P'$ term is inverted. These structures of Mo I closely resemble the term structure which has been found for Cr[22] but in Mo the low metastable terms are less widely separated from each other than in Cr.

TABLE 9. *Multiplets in the Mo* I *Spectrum*

	$^5D_0$	176.94	$^5D_1$	311.53	$^5D_2$	404.12	$^5D_3$	487.90	$^5D_4$
$^5F_5$									3405.93(7)
									29352.20
303.00									
$^5F_4$							3384.62 (8)		3441.45 (3)
							29536.95		29049.25
171.14									
$^5F_3$					3358.13 (9)		3404.35 (3)		3461.84 (1)
					29769.96		29365.82		28878.11
192.45									
$^5F_2$			3344.75 (8)		3380.99 (7)		3426.79 (3)		
			29889.02		29577.31		29173.49		
20.21									
$^5F_1$	3327.31 (7)		3347.02 (6)		3382.29 (2)				
	30045.73		29868.76		29557.29				
	$^5P_1'$	−123.30	$^5P_2'$	−127.30	$^5P_3'$				
$^5F_4$					4315.40 (1)				
					23166.33				
171.14									
$^5F_3$			..... ?		4347.47 (1)				
			22867.9		22995.43				
192.45									
$^5F_2$	4432.89 (1)		4408.81 (1)		4384.20 (2)				
	22552.34		22675.53		22802.78				
20.21									
$^5F_1$	4436.88 (3)		4412.77 (4)						
	22532.06		22655.14						

[20] Kiess, Journ. Wash. Acad. Sci., *13*, p. 218; 1923.
Kiess, Sci. Pap. Bur. Stand, *19*, p. 113; 1923.
[21] Catalán, Anales Soc. Esp. Fis. y Quim., *21*, p. 213; 1923.
[22] Kiess, J.O.S.A. & R.S.I., *10*, p. 287; 1925.

TABLE 9—*Continued*

	$^5G_2$ 51.88	$^5G_3$ 54.88	$^5G_4$ 36.70	$^5G_5$ 43.81	$^5G_6$
$^5F_5$			..... ?	..... ?	4019.79 (3)
			24950.7	*24914.0*	24870.17
303.00					
$^5F_4$		..... ?	4056.03 (5)	4062.09 (6)	
		24702.6	24647.72	24610.96	
171.14					
$^5F_3$	..... ?	4075.26 (3)	4084.39 (8)		
	24583.3	24531.39	24476.57		
192.45					
$^5F_2$	4098.75 (5)	4107.48 (8)			
	24390.84	24339.01			
20.21					
$^5F_1$	4102.16 (7)				
	24370.57				

Mo II. Table 10 contains multiplets which have been found in the quartet and sextet systems of the spark spectrum of Mo. These resemble similar multiplets which we have already published for CrII. The prominent lines of Mo II, which are of importance for spectrochemical analysis and which have the character of *raies ultimes* of the ionized atom, occur, as in Cr II, in a ^6D–^6F multiplet. But in Cr II, the term ^6S has been found recently[23] to be the lowest term , and accordingly a similar term is assumed to be the lowest term of Mo II.

TABLE 10. *Multiplets in the Mo* II *Spectrum*

	$^6D_1$ 250.70	$^6D_2$ 383.15	$^6D_3$ 482.90	$^6D_4$ 560.46	$^6D_5$
$^6D_5'$				2644.36 (12)	2684.15 (10)
				37805.02	37244.64
402.90					
$^6D_4'$			2638.76 (10)	2672.85 (10)	2713.52 (5)
			37885.24	37402.19	36841.64
310.33					
$^6D_3'$		..... ?	2660.58 (10)	2694.19 (6)	
		37957.8	37574.63	37092.13	
−200.00					
$^6D_2'$	2602.81 (5)	..... ?	2646.49 (8)		
	38408.51	*38157.8*	37774.63		
242.47					
$^6D_1'$	2619.35 (3)	2636.67 (8)			
	38166.04	37915.41			

[23] Kiess and Laporte, Science, *63*, p. 234; 1926.

TABLE 10—*Continued*

	$^6D_1$	250.70	$^6D_2$	383.15	$^6D_3$	482.90	$^6D_4$	560.46	$^6D_5$
$^6F_6$									* 2816.16 (20)
									35498.89
960.27									
$^6F_5$							* 2848.24 (12)		2894.46 (5)
							35099.17		34538.62
767.49									
$^6F_4$					* 2871.52 (10)		2911.92 (10)		2960.24 (2)
					34814.57		34331.58		33771.23
617.76									
$^6F_3$			2891.00 (4)		2923.40 (12)		2965.28 (3)		
			34579.94		34196.80		33713.84		
466.10									
$^6F_2$	2909.12 (8)		2930.50 (4)		2963.80 (4)				
	34364.61		34113.85		33730.69				
294.90									
$^6F_1$	2934.30 (5)		2956.96 (3)						
	34069.69		33818.97						

	$^4D_1$	287.15	$^4D_2$	453.04	$^4D_3$	701.94	$^4D_4$
$^4P_3$			..... ?		4184.39 (2)		4311.06 (5)
			24344.7		23891.67		23189.64
981.48							
$^4P_2$	4227.07 (2)		4279.04 (10)		4363.65 (10)		
	23650.39		23363.17		22910.19		
814.06							
$^4P_1$	4377.77 (10)		4433.51 (8)				
	22836.26		22549.18				
$^4D_4'$					3835.35 (2)		3941.54 (10)
					26065.87		25363.64
600.80							
$^4D_3'$			3857.15 (3)		3925.84 (3)		..... ?
			25918.56		25465.07		*24763.0*
385.78							
$^4D_2'$	3871.87 (2)		3915.45 (3r)		3986.21 (6)		
	25820.02		25532.65		25079.42		
242.58							
$^4D_1'$	3908.61 (3)		3953.00 (3)				
	25577.35		25290.15				
$^4F_5$							3652.40 (9)
							27371.46
968.33							
$^4F_4$					3688.31 (15)		3786.36 (6)
					27105.05		26403.13
484.93							
$^4F_3$			3692.64 (10)		3755.50 (5)		3857.20 (3)
			27073.19		26620.10		25918.22
359.15							
$^4F_2$	3702.49 (8)		3742.29 (6)		..... ?		
	27001.20		26714.04		*26261.0*		

Eka-manganese: This long sought for element (atomic No. 43) has recently been isolated by Noddack and Tacke[24] and its identity appears to be established by the measurement of three lines in its x-ray spectrum. So far as we know, the optical spectra have not yet been described, but it may confidently be expected that the arc and spark spectra will contain even and odd multiplicities respectively like those of the analogous element, manganese, because in the same way that the discoverers have interpolated many of the physical and chemical properties from the periodic table, the optical properties of this new element may be qualitatively derived from its atomic number.

Ru I: The arc spectrum of ruthenium is being investigated by Meggers and Laporte[25] who have already indicated that the majority of the strong lines are contained in a quintet system whose lowest level was tentatively called ^5D from analogy with the arc spectrum of iron. Zeeman effect measurements by Sommer[26] indicate that this term is rather ^5F, i.e., all quantum numbers are to be increased by one unit. An extensive analysis containing the main features of the quintet and triplet systems has been published.[27] A few multiplets, including one which contains the *raies ultimes*, are given in Table 11.

TABLE 11. *Multiplets in the Ru* I *Spectrum*

	$^5F_5$	1190.8	$^5F_4$	900.9	$^5F_3$	621.7	$^5F_2$	392.2	$^5F_1$
$^5G_6$	* 3498.95(50R)								
	28571.82								
1707.9									
$^5G_5$	3301.59 (8)		* 3436.75 (30R)						
	30279.75		29089.02						
−388.8									
$^5G_4$	3344.53 (3)		3483.32 (4)		3596.17 (20)				
	29891.04		28700.06		27799.45				
646.2									
$^5G_3$			3406.59 (2)		3514.50 (3)		3593.03 (20)		
			29346.46		28445.41		27823.74		
421.8									
$^5G_2$					3463.14 (3)		3539.37 (4)		3589.23 (5)
					28867.24		28245.54		27853.25

[24] Noddack and Tacke, Naturwissenschaften, *13*, p. 567; 1925.
[25] Meggers and Laporte, Science, *61*, p. 635; 1925.
[26] Sommer, Naturwissenschaften, *13*, p. 840; 1925.
[27] Meggers and Laporte, Journ. Wash. Acad. Sci. *16*, p. 143; 1926

TABLE 11—*Continued*

	$^5F_5$ 1190.8	$^5F_4$ 900.9	$^5F_3$ 621.7	$^5F_2$ 392.2	$^5F_1$
$^5F_5'$	3728.03 (10R)	3901.24 (4)			
	26816.25	25625.62			
1198.7					
$^5F_4'$	3568.47 (1)	3726.93 (10R)	3856.39 (3)		
	28015.21	26824.10	25923.66		
875.5					
$^5F_3'$		3609.10 (2)	3730.44 (4)	3819.04 (4)	
		27699.90	26798.87	26177.21	
536.9					
$^5F_2'$			3657.17 (2)	3742.29 (10)	3798.06 (3)
			27335.79	26714.04	26321.78
266.2					
$^5F_1'$				3705.36 (2)	3760.03 (4)
				26980.27	26587.98
$^5D_4$	3799.34 (8)	3979.44 (5)	4127.46 (3)		
	26312.91	25122.06	24221.19		
1194.0					
$^5D_3$		3798.90 (8)	3933.55 (4)	4032.21 (3)	
		26316.00	25415.16	24793.30	
969.2					
$^5D_2$			3790.50 (10)	3882.00 (3)	3942.06 (3)
			26374.26	25752.62	25360.28
652.9					
$^5D_1$				3786.05 (10)	3843.07 (3)
				26405.30	26013.40
451.1					
$^5D_0$					3777.58 (3)
					26464.50

Ru II: The spark spectrum of Ru has not been examined for regularities. It is now being investigated at the Bureau of Standards where a complete list of spark lines is being prepared.

Rh: The wave-number system of rhodium was investigated[28] in 1901 by C. P. Snyder who found it possible to represent 476 lines in a table of 19 columns and 54 rows. The interpretation of his table is now quite simple; his wave-numbers result from the combination of low energy levels (vertical columns) with higher levels (horizontal rows), the relative inner quantum numbers to be associated with the levels being determined from the combinations and selection rules for j and l. On this basis we have selected from Snyder's table three multiplets reproduced in our table 12, which includes a classification of the *raie*

[28] Snyder, Astroph. Journ., *14*, p. 179; 1901.

ultime of this spectrum. An extensive investigation of the arc spectrum of rhodium is being made by Sommer who in a preliminary note states[29] that doublets, quartets and inter-system combinations have been found, the quartet F term with separations 874.7, 1068.2 and 1529.9 being the lowest in the energy diagram.

The spark spectrum of rhodium has not yet been analysed.

TABLE 12. *Multiplets in the Rh I Spectrum*

	$^4F_5$ 1529.9	$^4F_4$ 1068.2	$^4F_3$ 874.7	$^4F_2$
$^4G_6$	* 3434.90(200R)			
	29104.62			
2509.1				
$^4G_5$	3162.27 (1)	3323.10 (50R)		
	31613.73	30083.76		
1430.5				
$^4G_4$	3025.41 (1)	3172.26 (4)	3283.57 (20R)	
	33043.78	31514.18	30445.92	
−800.7				
$^4G_3$		3254.96 (2)	3372.26 (8)	3474.80 (20)
		30713.52	29645.22	28770.43
$^4F_5'$	3396.81 (100R)	3583.09 (10)		
	29430.97	27900.94		
435.4				
$^4F_4'$	3347.30 (1)	3528.03 (30)	3666.24 (15)	
	29866.27	28336.36	27268.16	
1608.2				
$^4F_3'$		3338.55 (8)	3462.04 (30)	3570.18 (10)
		29944.54	28876.46	28001.83
802.9				
$^4F_2'$			3368.38 (5)	3470.67 (20)
			29679.37	28804.66
$^4D_4$	3692.36 (50)	3913.49 (4)	4084.30 (2)	
	27075.27	25545.43	24477.11	
1784.3				
$^4D_3$		3658.00 (50)	3806.76 (10)	3937.90 (1)
		27329.59	26261.63	25387.08
1537.6				
$^4D_2$			3596.17 (20)	3713.03 (10)
			27799.46	26924.55
749.5				
$^4D_1$				3612.47 (15)
				27674.03

Pd: Bechert and Catalán have classified[30] a large part of the arc spectrum of palladium, and have indicated that singlet and triplet

[29] Sommer, Naturwissenschaften, *13*, p. 392; 1925.

[30] Bechert and Catalán, Anales Soc. Esp. Fis. y Quim., *23*. p. 457; 1925.

systems are present, the lowest energy being represented by a singlet S term. Beals has recently published[31] Zeeman-effect data for Pd I lines which enabled him to identify a number of terms in the singlet and triplet systems. He lists his terms as regular, an arbitrary value of 60000.0 being assigned to a $^3D_1'$ level and the other terms being calculated from it. In this manner the values 14257.9, 20821.9, 22012.7, and 24351.7 were obtained respectively for $^1S_0$, $^3D_3$, $^3D_2$ and $^3D_1$ levels. Observations made at the Bureau of Standards on the under-water spark absorption spectrum of Pd show that the strongest lines involve these latter levels which must, therefore, be regarded as low in the energy diagram. Analogy with the arc spectrum of Ni also makes it probable that the spectral terms of Pd I are inverted, so that Beals' table of relative terms must be reversed and $^1S_0$ becomes the lowest level.

So far as we know, the spark spectrum of palladium has not yet been examined for regularities.

III. DISCUSSION

With the aid of Landé's rules for the Zeeman-effect and term structure of multiplets, the classification of complex spectra has made remarkable progress, and in many cases the rules have been found to hold with extraordinary exactness, although they were derived semi-empirically as approximations. As the spectral classifications were extended to the heavier atoms, however, the qualitative nature of these rules became more apparent; the deviations in some cases were so large that it was difficult to interpret them as such. Examples, selected from our work on the spectra discussed above, will now be given for the interval ratios of levels in complex terms, and for the Zeeman-effect of the spectral lines. Sufficient quantitative data are not yet available, but it may be expected that the rules governing intensity relations of lines in multiplets will only be approximations for the heavier elements.

(*a*) *Interval ratios.* The actual and theoretical ratios of the level separations of various complex terms are presented in Table 13. For the lighter elements the rule is generally closely approximated in the lowest levels, and for the higher terms with largest values of l quantum numbers. But with increasing atomic number deviations from the rule occur in all types of levels. In fact, certain levels have been found in which the separations are qualitatively the reverse of those required by the rule.

[31] Beals, Proc. Roy. Soc. London, *109*A, p. 369; 1925.

TABLE 13. *Interval ratios of spectral terms*

Spectrum	Term	Observed ratios	Theoretical ratios
YI	$^4D'$	7.0 : 2.5 : 1.4	7 : 5 : 3
	^4F	9.0 : 7.4 : 5.5	9 : 7 : 5
	$^4F'$	9.00 : 7.06 : 5.00	9 : 7 : 5
	$^4G'$	11.00 : 9.05 : 7.10	11 : 9 : 7
YII	^3D	3.0 : 1.5	3 : 2
	$^3F'$	4.00: 3.15	4 : 3
	$a\,^3P$	2.0 : 0.8	2 : 1
	^3F	4.0 : 1.4	4 : 3
	$^3D'$	3.0 : 0.8	3 : 2
	$b\,^3P$	2.00: 0.95	2 : 1
ZrI	^3F	4.0 : 3.4	4 : 3
	$^3F'$	4.0 : 3.1	4 : 3
	^3D	3.0 : 2.18	3 : 2
	^3G	5.0 : 6.86	5 : 4
	^5F	5.0 : 3.36 : 2.52 : 1.70	5 : 4 : 3 : 2
	$^5F'$	5.0 : 3.69 : 2.70 : 1.80	5 : 4 : 3 : 2
	^5D	4.0 : 3.23 : 2.30 : 1.07	4 : 3 : 2 : 1
	^5G	6.0 : 5.65 : 4.95 : 4.56	6 : 5 : 4 : 3
ZrII	^4F	9.0 : 7.22 : 5.06	9 : 7 : 5
	$^4F'$	9.0 : 10.18 : 11.29	9 : 7 : 5
	^4D	7.0 : 8.80 : 6.77	7 : 5 : 3
	^4G	11.0 : 10.71 : 10.64	11 : 9 : 7
CbII	^5D	0.5 : 3.0 : 2.3 : 1.3	4 : 3 : 2 : 1
	$^5F'$	5.0 : 1.5 : 4.2 : 2.3	5 : 4 : 3 : 2
	^5F	5.0 : 4.2 : 3.3 : 2.3	5 : 4 : 3 : 2
	^5G	6.0 : 5.2 : 4.4 : 3.	6 : 5 : 4 : 3
MoI	^5D	4.0 : 3.31 : 2.55: 1.45	4 : 3 : 2 : 1
	^5F	5.0 : 2.82 : 3.17: 0.33	5 : 4 : 3 : 2
	^5G	6.0 : 5.04 : 7.52: 7.10	6 : 5 : 4 : 3
	$^5P'$	3.0 : 2.90	3 : 2
MoII	^4D	7.0 : 4.52 : 2.86	7 : 5 : 3
	$^4D'$	7.0 : 4.50 : 2.83	7 : 5 : 3
	^4P	5.0 : 4.15 :	5 : 3
	^4F	9.0 : 4.50 : 3.34	9 : 7 : 5
	^6D	9.0 : 7.75 : 6.12: 4.03	9 : 7 : 5 : 3
	$^6D'$	9.0 : 6.90 : −4.44: 5.40	9 : 7 : 5 : 3
	^6F	11.0 : 8.80 : 7.08: 5.34: 3.38	11 : 9 : 7 : 5 : 3
RuI	^5F	5.0 : 3.8 : 2.6 : 1.8	5 : 4 : 3 : 2
	$^5F'$	5.0 : 3.8 : 2.3 : 1.2	5 : 4 : 3 : 2
	^5D	4.0 : 3.2 : 2.2 : 1.5	4 : 3 : 2 : 1
	^5G	10.6 :−2.4 : 4.0 : 2.6	6 : 5 : 4 : 3

(*b*) *Zeeman-effects.* Deviations from the Landé *g* values for the splitting of spectral levels in low magnetic fields have already been pointed out by Goudsmit[32] for lanthanum spark lines and by Laporte[33] for tungsten arc lines. These two elements occur in the sixth horizontal row of the periodic table, but many of the magnetic spectral resolutions for elements in the preceding period, the one we are mainly concerned with in this paper, show marked deviations from the theoretical patterns. These deviations appear to be a function of two factors, they become larger with increasing atomic number, and for a given spectrum they are usually small for the lowest level but increase progressively for levels which rise in the energy diagram.

As an example of changing *g* values with atomic number we may compare the Zeeman patterns of similar combinations in the spark spectra of Sc_{34} (21), Y^{35} (39) and La^{36} (57) as follows:

Theoret.	$^3D_3-{}^3F_3$	λ	(0.50, **1.00**) 0.17,	**0.67, 1.17,** 1.67
Sc II	$^3D_3-{}^3F_3$	3651.80	(0.57, **1.02**)	**0.57, 1.02,** 1.62
Y II	$^3D_3-{}^3F_3$	3818.37	(0.38, **0.77**) 0.37,	**0.74, 1.14,** 1.52
La II	$^3D_3-{}^3F_3$	4196.55	(0.39, **0.60**) 0.52,	**0.81, 1.14,** 1.41

The *p* and *s* components which are nearly equal were not resolved in the observations on Sc II; if they had been separated the pattern would probably have resembled the theoretical one very closely. The *g* values of the others deviate from the theoretical values in the following manner:

	Theoretical	Y I	La II
$g\,{}^3D_3$	0.67	0.75	0.84
$g\,{}^3F_3$	1.17	1.14	1.14

When the trend of such deviations is recognized one can adopt a slightly modified set of *g* values and thus extend the spectral analysis for the heavier elements. In this manner, for example, the analysis of La II, for which only two complete multiplets have been published, was extended. We give as an example a multiplet containing the line dis-

[32] Goudsmit, Proc. Roy. Acad. Sci., Amsterdam, *28*, No. 1, 1924.
[33] Laporte, Naturwissenschaften, *13*, p. 627; 1925.
[34] Goudsmit, van der Mark and Zeeman, Proc. Roy. Acad. Sci., Amsterdam, *28*, No. 2, 1925.
[35] Meggers, Journ. Wash. Acad. Sci., *13*, p. 419; 1924.
[36] Goudsmit, Proc. Roy. Acad. Sci. Amsterdam, *28*, No. 1, 1924.

cussed above, because it also contains the La II *raies ultimes* which were heretofore unclassified.

	$^3D_3$	658.8	$^3D_2$	696.5	$^3D_1$
$^3F_4$	*3949.10 (50)				
	25315.10				
1727.9					
$^3F_3$	4238.40 (20)		*4123.22 (30)		
	23587.21		24246.06		
423.6					
$^3F_2$	4315.91 (2)		4196.55 (10)		4077.34 (15)
	23163.61		23822.43		24518.93

As illustrations of the deviations of the g values with position of the term in the energy diagram, we give the following examples from Zr I.

Wave Length	Term Combination	Observed Zeeman pattern		Empirical g values ± 0.03		Theoretical Zeeman pattern		Theoretical g values	
6127.49	$a^3F_4-a^3F_4'$	(0.00)	1.26	1.25	1.25				
3890.32	$a^3F_4-b^3F_4'$	(0.28)	1.21	1.25	1.17	(0.00)	1.25	1.25	1.25
3663.64	$a^3F_4-c^3F_4'$	(0.35)	1.21	1.25	1.15				
6143.23	$a^3F_3-a^3F_3'$	(0.00)	1.09	1.08	1.08				
3863.87	$a^3F_3-b^3F_3'$	(0.00)	1.11	1.08	1.08	(0.00)	1.08	1.08	1.08
3623.67	$a^3F_3-c^3F_3'$	(0.26)	1.07	1.08	0.98				
6134.58	$a^3F_2-a^3F_2'$	(0.00)	0.68						
3835.96	$a^3F_2-b^3F_2'$	(0.00)	0.69	0.67	0.67	(0.00)	0.67	0.67	0.67
3586.26	$a^3F_2-c^3F_2'$	(0.00)	0.70						

(*c*) *Raies Ultimes.* In the paper, already referred to,[37] which discussed spectral structures for elements of the first long period, some conclusions were reached concerning the *raies ultimes*,[38] the most sensitive lines for the purpose of spectrographically detecting a chemical element. In spark spectra, it was observed that the most sensitive lines occurred without exception among terms belonging to systems of the largest permanent multiplicity which the spectrum possesses, and in every case these *raies ultimes* involved the lowest energy level, i.e., the normal state of the ionized atoms. Less uniform relations to term multiplicities and magnitudes were noted for the *raies ultimes* of arc spectra, and in particular what appeared to be an exception to the rule that these lines

[37] Meggers, Kiess and Walters, Jr., J.O.S.A. & R.S.I., *9*, p. 355; 1924.
[38] de Gramont, Comptes Rendus, *171*, p. 1106; 1920.

are related to the normal state of the atom was pointed out in the Ti I spectrum in which the group $^5F-{}^5G$ (4981.73 to 5014.28A) was found by de Gramont to be much more sensitive than the lines $^3F-{}^3F'$ (5173.74, 5192.97, 5210.39A) although the ^3F term is 6500 wave-number units lower in the energy diagram than ^5F. A fortunate accident has made it possible to correct this statement. Although the Zr measurements mentioned above were made on material of very high purity, it was later found that the spectrum contained some lines belonging to Ti, and upon identification of the latter it was seen that the most intense lines of the Ti impurity were $^3F-{}^3G$ (3635.47, 3642.68, 3653.49A). It was a mistake to compare the sensitivity of $^5F-{}^5G$ with that of $^3F-{}^3F'$ instead of $^3F-{}^3G$. It now appears to be a general rule that true *raies ultimes* involve the term with lowest energy in the spectrum, although in rare instances where there are two or more low terms of nearly the same value, but with quite different inner quantum numbers, the empirical *raie ultime* may involve the higher level if this has the larger quantum numbers. Thus in Pd I, the line 2448.16A, ($^1S_0-{}^1P_1$), involves the lowest level but the line 3404.58A, ($^3D_3-{}^3F_4$), is more intense and spectrochemically more sensitive, possibly on account of the larger l and j values which characterize its terms.

Laporte and Meggers have pointed out[39] that, excepting the arc spectra of metals of the Al group, the combination which gives rise to *raies ultimes* is with a term having one unit larger l quantum number. The latter term is usually the first non-metastable excited state which is permitted to combine as l decreases one unit to that of the normal state, but this is not always the case for in Ti I we have another combination $^3F-{}^3G$ (4656.47, 4667.59, 4681.91A) which is much inferior in sensitivity to the one given above. All that has been said about the *raies ultimes* of Ti I applies also to Zr I because of the close parallelism of the two spectra.

The simple rule for *raies ultimes* appears to be obeyed very widely indeed, and in some of the spectra discussed above it has been important for the identification of the lowest level. Considering the wide variations in the spectral sensitivity of photographic plates, the selective action of spectrographs, and other difficulties in the way of the empirical determination of *raies ultimes* in complex spectra, the almost unfailing accuracy with which de Gramont described these must be regarded with great admiration.

[39] Laporte and Meggers, J.O.S.A. & R.S.I., *11*, p. 459; 1925.

TABLE 14. *Systems of spectral structures for thirteen elements of the fourth period*

(a) Arc Spectra, Neutral Atoms

Column	I	II	III	IV	V	VI	VII	VIII			I	II	III
Element	K-19	Ca-20	Sc-21	Ti-22	V-23	Cr-24	Mn-25	Fe-26	Co-27	Ni-28	Cu-29	Zn-30	Ga-3
Systems and low term quantum numbers p^l	2^1	1^1 3	2^2 4	1 3^4 5 6	2 4^4	3 5 7^1	4 6^1 8	3 5^2 7	2 4^4 6	1 3^4 5	2^1 (4)	1^1 3	2^2

(b) Spark Spectra, Ionized Atoms

Column	I	II	III	IV	V	VI	VII	VIII			I	II	III
Element	K-19	Ca-20	Sc-21	Ti-22	V-23	Cr-24	Mn-25	Fe-26	Co-27	Ni-28	Cu-29	Zn-30	Ga-31
Systems and low term quantum numbers p^l	?	2^1	1 3^3	2 4^4	1? 3 5^4	2 4 6^1	3? 5 7^1	2? 4 6^3	(1) (3) $(5)^{(4)}$	(2) $(4)^{(4)}$	$(1)^{(3)}$ (3)	2^1	?

TABLE 15. *Systems of spectral structures for thirteen elements of the fifth period*

(a) Arc Spectra, Neutral Atoms

Column	I	II	III	IV	V	VI	VII	VIII			I	II	III
Element	Rb-37	Sr-38	Y-39	Zr-40	Cb-4 1	Mo-42	?-43	Ru-44	Rh-45	Pd-46	Ag-47	Cd-48	In-49
Systems and low term quantum numbers r^j	2^1	1^1 3	2^3 4	1? 3^4 5	2? 4 6^3	3? 5 7^1	(4) $(6)^{(a)}$ (8)	3 5^4 (7)	2 4^4 (6)	1^1 3 (5)	2^1 (4)	1^1 3	2^2

(b) Spark Spectra, Ionized Atoms

Column	I	II	III	IV	V	VI	VII	VIII			I	II	III
Element	Rb-37	Sr-38	Y-39	Zr-40	Cb-41	Mo-42	?-43	Ru-44	Rh-45	Pd-46	Ag-47	Cd-48	In-49
Systems and low term quantum numbers r^j	?	2^1	1 3^3	2 4^4	(1) (3) 5^3	(2) 4 $6^{(1)}$	(3) (5) $(7)^{(1)}$	(2) (4) $(6)^{(a)}$	(1) (3) $(5)^{(a)}$	$(2)^{(a)}$ (4)	$(1)^{(1)}$ (3)	2^1	?

(*d*) *Summary.* In conclusion we give Tables 14 and 15 in which spectral structures for neutral and ionized atoms of the fourth and fifth periods of elements are summarized for purposes of comparison. The numbers 1, 2, 3, 4, etc., represent the maximum multiplicities (quantum number r) in the spectral terms belonging to the corresponding system of spectral structures, singlets, doublets, triplets, quartets, etc. The exponent borne by one number for each spectrum represents the l quantum number of the largest spectral term or lowest energy level. These exponents 1, 2, 3, 4, etc., correspond respectively to the term types, *S*, *P*, *D*, *F*, etc., as stated above. Considerations of symmetry first suggested for these tables the inclusion of 13 elements of each long period; this procedure later found justification in the new theoretical developments mentioned above. The numbers enclosed in parenthesis are suggested by the symmetry, but they are not yet established in the analysis of the corresponding spectra. We trust that within a relatively short time the remaining empirically unknown or uncertain spectral structures for these elements will be revealed.

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Reflection from very thin Sputtered Films of Ag and Cu.—Richter illuminated thin foils of mica, half covered with sputtered silver or copper and half uncovered, by normally-incident light from a Nernst filament, and resolved the normally-reflected light by a spectroscope, obtaining spectra barred with interference-fringes. Comparing the locations of the fringes from the uncovered half of the film with those of the corresponding fringes from the covered half, and assuming that the displacements of the latter relatively to the former are due entirely to phase-shifts occurring at the metal film, he determines these latter and compares them with values computed according to Drude's formula by conceiving the film as a continuous medium having the same optical constants as a very thick film produced likewise by sputtering. The thicknesses of the various films (determined by combining iodine with the metal and measuring the thickness of the resulting transparent film interferometrically) range from 2 to 150 $m\mu$. For films thinner than 20 $m\mu$ the different observations are wildly scattered; for thicker films they agree pretty well with the calculated values, which is taken to mean that films as thin as 20 or even 15 $m\mu$ may be treated as continuous media with the same optical constants as thicker ones. However, earlier work upon films of these and other metals indicate that this conclusion is not correct; possibly the fact that the previous films were sputtered onto glass had something to do with it. [J. Richter, Leipzig; Ann. d. Phys. 77, pp. 81-97; 1925.]

KARL K. DARROW

Heating Effect of the Gamma-rays of RaB and RaC.—This quantity was determined by an ingenious method, in which the quantity actually measured is the difference between the rates of development of heat in a piece of Al and a piece of Pb, similar and similarly placed with respect to the sample of radioactive matter enclosed in a thick-walled copper tube; so that the energy of the α-rays and β-rays is converted into heat in the copper and oozes almost equally into the two pieces of metal, and the differential effect is due almost exclusively to the difference between the amounts of gamma-ray absorption in the Al and the Pb. Calibration is effected by dissipating known amounts of electrical energy in wires embedded within the pieces of Al and Pb and within the copper tube. A considerable amount of calculation is nevertheless necessary, particularly in order to determine the fractions of gamma-ray energy which escape absorption in the Al and the Pb (a process which involves not-altogether-certain assumptions about the relative amounts of electromagnetic energy scattered, or converted into kinetic energy when scattering occurs, or converted into potential energy when electrons are extracted from atoms—which appear all to be of about the same order of magnitude). The eventual result is that "The amount of RaB and RaC that is in equilibrium with 1g of Ra emits 8.6 cal/hour in the form of gamma-rays" the estimated precision being 5%. The authors further estimate, using incomplete and somewhat uncertain data, that this amount is to be divided between RaB and RaC in the ratio 8.6/77. [C. D. Ellis and W. A. Wooster, Cavendish; Phil. Mag. *50*, pp. 521-536; 1925.]

KARL K. DARROW

Effect of Temperature and of Admixed Cd, In and Mg on the Electrical Resistance of Hg.—The measurements were made by a bridge method upon mercury and certain liquid amalgams contained in capillaries; absolute values of resistivity were not determined. Measurements on "pure" mercury at nine temperatures from 0° to 297°C are incompatible with a quadratic resistance vs. temperature formula but agree when a cubic term is introduced. (Previous data at temperatures beyond 100° are so old as probably to count for little). As for the amalgams, the effect (percentage change in conductivity) of In up to 3% and of Mg up to about 0.25% (beyond which the metals do not mix) remains sensibly proportional to the quantity of added metal; the effect of Cd is initially proportional to the added quantity, but a quadratic term must be used in addition to express the variation up to 4% of added Cd. It is interesting to note that Skaupy's rule, that equal numbers of added atoms of different metals produce equal changes in the conductivity of Hg, is valid for Cd and In; but the value for Mg is 40% higher than the rule would imply. [E. J. Williams, Swansea; Phil. Mag. *50*, pp. 589-599; 1925.]

KARL K. DARROW

URANIUM AS AN ACTIVATOR

By Edward L. Nichols and Mabel K. Slattery

In luminescence uranium is chiefly known as a component of the uranyl salts, all or nearly all of which are strongly fluorescent alike in the crystalline form and in aqueous solution. Compounds in which uranium is not associated with oxygen in the radical UO_2 (uranyl) as is well known are in general, non luminescent. The best known exception to the above statement is canary glass in which the uranium is probably present as a silicate in dilute solid solution in the glass. There are to be sure occasional references to uranium as a possible activator in the preparation of fluorescent combinations. Gans and Vanino[1] for example mention nitrates of uranium as increasing the brightness of luminous paints made of strontium or barium sulphates, but as inactive when calcium sulphate is used. Miss Engle of the University of Illinois, in an investigation not yet published, lists uranium as one of the possible activators of zinc silicate.

It is the purpose of the present paper to describe the properties of other luminescent solid solutions in which traces of a uranium salt are present and in which that element serves as the activator.

SODIUM PHOSPHATE AS A SOLVENT

When microcosmic salt ($HNaNH_4 \cdot PO_4 4H_2O$) is fused, either in a crucible or on the platinum wire, the resulting glasslike bead shows no appreciable luminescence under photo excitation or in the cathode tube. The addition of a uranium compound, even in quantities too small to give the bead body color, results however in a bright green luminescence. Excessive heating destroys the power to respond to photo- or cathodo-excitation, and that this is due to the expulsion of water of constitution is evident since on dissolving in water and heating again to complete dryness the luminescent power is restored. Merely allowing the hygroscopic salt to absorb the moisture from the air is not sufficient. The salt containing water must be subjected to suitable heat treatment before it will again fluoresce.

The relation of brightness to concentration of a series of these preparations, as measured by means of an optical pyrometer of the heated filament type, is shown in Fig. 1 in which abscissae, plotted to a log-

[1] Gans and Vanino, Journal für Praktische Chemie, 1905.

arithmic scale, are molecules of the solvent per molecule of uranyl phosphate and ordinates are relative intensity of luminescence when the bead was excited by the radiation of a mercury arc filtered through a layer of deep purple glass (Corning). The *Bruninghaus optimum* is

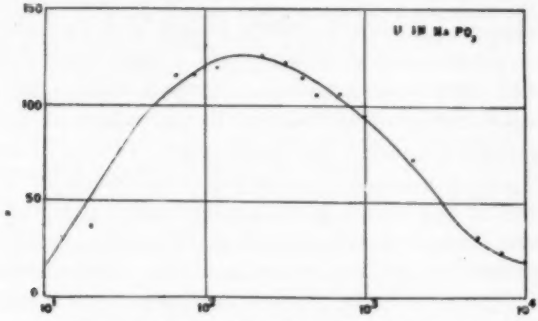


FIG. 1. *Curve for the optimum; $NaPo_3$ as solvent*

well defined at about .005 mole-fractions. At a concentration of .0001 the brightness was still nearly 1/8 of that of the maximum concentration.

The fluorescence spectrum of this solid solution of uranium, probably in the form of the phosphate, shows three broad bands (*A*, *B*, *C*, Fig. 2)

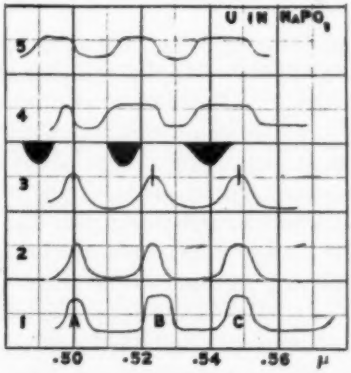


FIG. 2. *Bands in the spectrum; $Na\ PO_3$ as solvent*

easily discerned with suggestions of a fourth and very feeble band in the yellow. Fig. 2 will serve to indicate the approximate location and width of these bands, compared with the intervening dark regions, as they appear after five different kinds of heat treatment:

1. The mixture, which was of the proportions to yield the optimum brightness, was heated in a platinum loop in the Bunsen flame until fusion occurred with formation of a bead. It was then immediately withdrawn from the flame and when cold was excited to fluorescence by the mercury arc through the screen of deep purple glass. Under these conditions bands *A*, *B* and *C*, as determined by locating their edges, were narrower than the intervening spaces and so far as could be seen had rather broad single crests. The suggestion of a fourth band, only one edge of which could be located, and that roughly, is indicated at the right.

2 and 3. Two subsequent brief heatings similar to that described above, and, like (1), not sufficient to produce a bead which was transparent when cooled, brought about no apparent changes in the spectrum excepting a more definite crest to bands *A* and *B* (see curves 2 and 3 in Fig. 2).

4. Upon further heating of the bead, just sufficient to clear it up and to render it transparent when cold, bands *B* and *C* were greatly broadened towards the shorter wave lengths, the edges on the side towards the red remaining unshifted. Band *A* however was still quite narrow.

5. The bead was returned to the flame and heated until it boiled no more. The result was to extend band *A* towards the blue until it was approximately as wide as *B* and *C* which were not further modified. As has already been noted prolonged heating beyond this stage renders the bead non-luminescent.

The diagram in Fig. 2 is intended to convey in a conventional way simply the location of the bands, the places of which correspond with those determined for a somewhat similar preparation in 1918,[2] their width, and the width of the intervening spaces; also the fact that they appear in the spectroscope to be about equally bright. To determine the more intimate structure detailed spectrophotometric measurements were made upon a bead the previous heat treatment of which corresponded approximately to stage (5) in Fig. 2.

The result, which is given in Fig. 3, reveals something of this structure. It was found, as was to be expected from our knowledge of the luminescence spectra of the uranyl salts, that what appear to the eye to be simple bands, (*A*, *B* and *C* Fig. 2) are made up of several narrow components. These are only partly revealed but since at the temperature of liquid air no further degree of resolution occurred, as had

[2] Nichols and Howes, Carnegie Publ., *298*, p. 142, 1919.

long since been found to be the case in the luminescence spectra of sodium phosphate[3] a partial analysis was attempted on the basis of the spectrophotometric curve (Fig. 3).

Starting with the two best defined crests as a basis, those at .5045 and .5188, see Table 1, we note that these have a frequency interval of 54. While there are no other crests revealed which are equally spaced with these, we find that assuming the existence of a set of crests thus spaced the next members come at .4912 on one side and at .5336 on the other and that these coincide with the very square shoulders towards the violet of the broad bands *A* and *C*. Such a hypothetical set is indicated by the four short vertical lines thus labelled in Fig. 3.

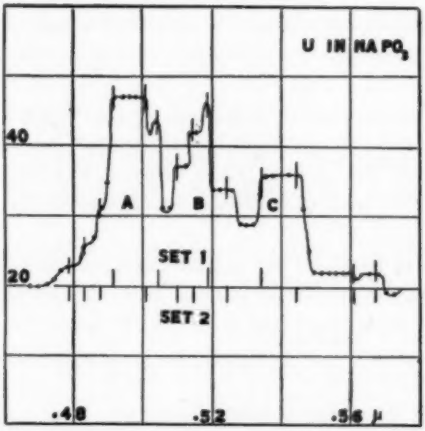


FIG. 3. *Spectrophotometric curve; Na PO_3 as solvent.*

If two crests, also clearly present between the two above mentioned at .5096μ and .5145μ—which are not in step with set 1 but which have a frequency difference of 18 (or 54/3) are made a starting point of another set, we find nine members which correspond with the other square shoulders of the broad unresolved bands or with minor inequalities in the curve suggestive of submerged components. These are indicated by another set of short vertical lines labelled "Set 2." Both sets are given in Table 1. The frequency intervals are of course all 18 or some exact multiple of that number.

The consideration of the structure of this spectrum of uranyl phosphate in sodium phosphate, necessarily incomplete because of the

[3] Nichols and Howes, l.c.

overlapping of the components, suffices to show the dissimilarity between the luminescence of this solid solution and that of the uranyl salts. While the broad bands, considered as single, are separated by an interval characteristic of the uranyl salts, (i.e. 88) and are made up of narrower submerged components, there is no obvious repetition

TABLE 1. *Components of the luminescence spectrum of uranyl phosphate in sodium phosphate at +20°C.*

Set 1			Set 2		
μ	$1/\mu\times10^3$	Δ	μ	$1/\mu\times10^3$	Δ
			.4790	2088	18
			.4830	2070	18
			.4873	2052	18
.4912	2036				54=18×3
		54=18×3	.5005	1998	
.5045	1982				36=18×2
			.5096	1962	
		54=18×3			18
			.5145	1944	
.5188	1928				36=18×2
		54=18×3	.5241	1908	
.5336	1874				72=18×4
			.5445	1836	
					54=18×3
			.5611	1782	
					18
			.5669	1764	

of the arrangement of these within the successive bands such as to give the striking and extraordinary homologous series found in the spectra of the uranyl salts. Whether if the spectrum could be resolved by cooling such an arrangement would appear cannot be determined from this preparation.

SODIUM BORATE AS A SOLVENT

A borax bead without admixture is nearly neutral. According to photographs made by Mr. A. P. Northrup in the course of an investigation as yet unpublished, a cathodo-luminescence in the blue and extending into the ultraviolet is to be detected only after prolonged exposure. The spectrum is continuous. When impregnated with traces of a uranium salt, however, borax has a well marked green fluorescence under photo-excitation.

The spectrum, as with sodium phosphate, is profoundly affected by the previous heat treatment. After a brief preliminary heating leaving the substance white and not fused three bands are present. These are slightly broader than in the phosphate under similar conditions.

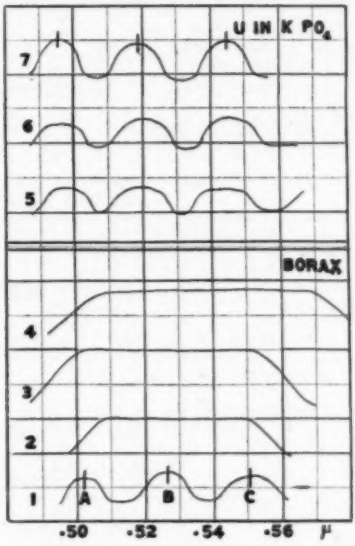


FIG. 4. *Bands in the spectrum; K PO_3 and borax as solvents.*

(Fig. 2, 1.) They are almost identical with these as to position however. See curve (1) in Fig. 4. We may assign to the crests the locations marked by the short vertical lines.

TABLE 2.

μ	$1/\mu \times 10^3$	Δ
.502	1992	
		88
.526	1904	
		88
.5505	1816	

The determination is necessarily rough but will suffice to indicate constancy of frequency difference and approximately the same interval as in Fig. 2. After heating the bead to fusion, but leaving it clouded, the bands are blended in one (Fig. 4, 2). Clearing the bead by further heating broadens the band in both directions (Fig. 4, 3). When excited

to luminescence at the temperature of liquid air the band is shifted towards the red *by at least 100A.* and further broadened. As with the solid solution in sodium phosphate, continued heating causes complete loss of fluorescence which is restored by the addition of water and suitable reheating.

POTASSIUM PHOSPHATE AS A SOLVENT

When potassium phosphate was substituted for sodium phosphate as the solvent of uranyl phosphate, the resulting bead was found to have a decidedly bluish green luminescence, a change due to a shift of the bands *A*, *B*, and *C* towards shorter wave lengths by about 65A. (See curves 5, 6 and 7 in Fig. 4).

After the first stage of heating the bead was clear, after the second it was clouded and after the third was clear again changes which probably corresponded to successive losses of water as the material went through the transformations: $KHPO_4 \cdot H_2O \rightarrow KHPO_4 \rightarrow KPO_3$. As will be seen from the curves no conspicuous modifications in the spectrum occurred excepting a slight shift of the bands towards the blue and an increase in the relative brightness of band *B* in the final stage. Further and more prolonged heating destroyed the luminescence which, as in the case of the previous preparations studied, could be restored by the addition of water and reheating.

The distance between crests (assigning to them the places indicated by the vertical lines) was 91, but the difference, as compared with the difference of 88 for sodium phosphate and borax, while probably real, is in some doubt because of the great width of the bands.

SODIUM FLUORIDE AS A SOLVENT

The brightest and most striking of the luminescent substances included in the present investigation are those in which sodium fluoride is used as a solvent. In color, at room temperature, instead of the green characteristic of the uranyl salts and of the other solid solutions in which uranium is the activator they are a *vivid yellow*.

So effective is uranium in sodium fluoride that with one molecule in ten million the luminescence is still easily measured. The optimum brightness occurs at a dilution of one molecule to two thousand as shown in Fig. 5 in which, as in the previous optimum curve (Fig. 1), in order to represent the great range covered by the measurements the curve is plotted to a logarithmic scale for the abscissae, and where abscissae are molecules of the solvent to one molecule of the activator.

The spectrum. Owing probably to the absence of water these preparations are not appreciably sensitive to differences of heat treatment. We have to do therefore essentially with only one spectrum for a given temperature of observation, and do not have to consider the various stages described in previous paragraphs.

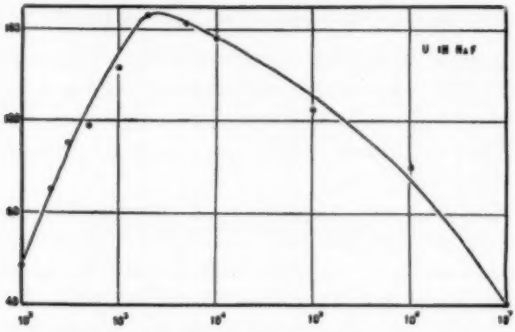


FIG. 5. *Curve for the optimum; Na F as solvent.*

At room temperature the appearance of the spectrum does not suggest any close relation to the well known spectra of the uranyl salts, in which the various bands are made up of similar components, the arrangement repeating itself over and over as we pass from red to violet. In the present case five rather broad bands are readily distinguished, with their group crests approximately as below. These are called *group crests* to distinguish them from the crests of their hidden components subsequently described.

TABLE 3. *Group crests*

Band	μ	$1/\mu \times 10^3$	Δ
A	.634	1577	
			73
B	.606	1650	
			81
C	.577	1731	
			64
D	.557	1795	
			71
E	.534	1872	

These bands are not of equal breadth nor are they equally spaced. There is a tendency to resolution but this does not manifest itself in the same manner in the different bands. The two inner and brightest

bands, in yellow-green and orange, are of by far the greatest intensity. *B* and *D* (.557μ) shows a single crest somewhat towards the violet from the center, while its neighbor *C* (.577μ) is obviously a doublet.

Instead of depicting these differences as has been done in Figs. 2 and 5 we may proceed at once to the results of the spectrophotometric measurements indicated in Fig. 6. Here two curves are given: (1) For a dilution of 1:2,000 (2) For a dilution of 1:100,000. It will be seen that these curves are similar excepting in such minor differences as may be ascribed to unavoidable variations in the intensity and quality of the excitation from the mercury arc (through purple glass). The ratio of

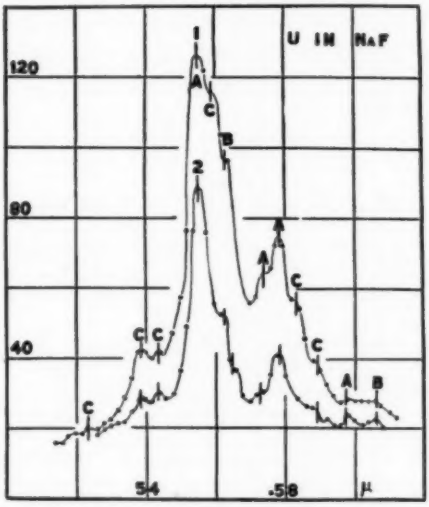


FIG. 6. *Spectrophotometric curves; NaF as solvent*
(1) 1:2000 (2) 1:100000.

brightness of the two is also obviously of the order indicated in the optimum curve (Fig. 5) for these two dilutions, i.e. about 3:2.

As to structure; we may readily pick out from the curves a number of more or less submerged components, and these (like those of the spectrum of the solution in sodium phosphate) can be ranged in sets with frequency differences which are multiples of the same or very nearly the same interval, i.e. 18. (See Table 4.)

The method of locating the short vertical lines in Fig. 6 which are intended to show such crests wherever the observations afford a suspicion of their whereabouts was as follows. It having been noted that the

two chief peaks on both curves, i.e. at .5555μ and .5785μ have a frequency difference of 72, which is a multiple of the interval 18 which had been found characteristic of the spectrum of uranyl phosphate in sodium phosphate, other members of a set having as frequency intervals multiples of 18 were sought for by inspection of the curves. These were marked by vertical lines (A) and recorded in Table 4 as Set A_1. Similarly a set (A_2) was formed from the minor crest at .6064, which crest is clearly indicated in curve 2, and a third set (B_1) was based upon the two crests at .5896 and .5834 which are 18 frequency units apart.

TABLE 4. *Components of the luminescence spectrum of uranyl fluoride in sodium fluoride, at 20°C*

Set A_1			Set A_2			Set B_1		
μ	$1/\mu\times10^3$	Δ	μ	$1/\mu\times10^3$	Δ	μ	$1/\mu\times10^3$	Δ
			.6064	1649				
					36			
.5974	1674		.5935	1685				
		54				.5896	1696	
								18
						.5834	1714	
.5785*	1728				90			
		18						
.5727	1746							72
		54	.5634	1775				
						.5599	1786	
.5555*	1800							54
						.5435	1840	
								18
						.5382	1858	
								54
						.5230	1912	

* The principal crests as shown in Fig. 6.

These three sets cover all the submerged crests which can be located with any degree of probability from the curves.

At the temperature of liquid air the luminescence spectrum of uranium in sodium fluoride, unlike those previously described in this paper, is resolved into narrow line-like components. The salient feature of this resolved spectrum is a group of three strong, equidistant bands with an underlying structure of relatively feeble intensity, some components of which are so weak as to be difficult objects in the field of the spectroscope.

This strong trio is indicated in Fig. 7 by the *tall* vertical lines A_0, A_0, A_0. The outer members are the same distance apart as the principal crests in the spectrum at 20°, the location of which is shown in Fig. 7 by the tall verticals *below the line*, A_1, A_1. From these they are however displaced nearly 11 frequency units towards the violet. Since the frequency difference is 72, these strong bands with the intermediate companion midway between them may be regarded as members of a set with the interval 18 and in fact four of the other bands of this spectrum (see Table 5) and the short vertical lines marked A_0 in Fig. 7 are found to belong to such a set. The remaining five bands upon which settings could be made form another set B_0 of like frequency interval.

The vertical lines below the horizontal line in Fig. 7 are plotted from Table 4. Of these the sets A_1 and B_1 have throughout the same dis-

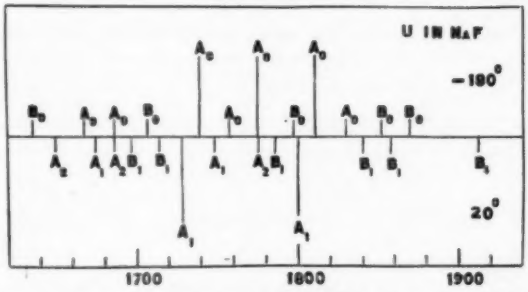


FIG. 7. *Components of spectrum at temperature of room and of liquid air; NaF as solvent.*

placement from the corresponding members of A_0 and B_0 as the principal peaks at 20° from the strong lines at −180°, i.e. (as pointed out above) about 11 frequency units, while two members of the three in set A_2 coincide, within the errors of observation, with A_0.

This coincidence indicates that the displacement on cooling *is not a shift* of the bands, in the ordinary sense, but is due to a subsidence of certain bands as we pass from room temperature to that of liquid air, and the enhancement of others. This is a phenomenon which has long since been found to be characteristic of the spectra of the uranyl salts.[4]

In the foregoing description of the method employed in the study of the fluorescence spectrum at room temperature, as has already been explained, the existence of a frequency interval of approximately 18 was assumed, and it was sought to determine how well such an interval

[4] Nichols and Howes, l.c. p. 68.

fitted the crests and submerged components of the spectrophotometric curve. In the case of the spectrum at $-180°$, however, where direct settings of the bands could be made to within about one frequency unit, the opposite and more usual method of direct readings was employed, the results of which are given in Table 5. That the two methods are about equally good appears from the uniformity of the displacements of A_1 from A_0 and of B_1 from B_0 throughout the spectrum. That the interval for $-180°$ is very close indeed to that assumed for 20°, may be shown by taking the distance between the end members of sets A_0 and B_0.

For A_0 we have: $1829.5-1667.6=161.9$ and $161.9/9=17.99$

For B_0 we have: $1869.2-1635.0=234.2$ and $234.2/13=18.02$

In Table 5 it will be seen that individual departures of the frequency interval from 18 or some exact multiple thereof are never as great as

TABLE 5. *Components of the luminescence spectrum of uranyl fluoride in sodium fluoride at $-180°$.*

Set A_0			Set B_0		
μ	$1/\mu\times10^3$	Δ	μ	$1/\mu\times10^3$	Δ
			.6116	1635.0	
.5996	1667.6				
		18.2			71.8=18×4−.2
.5932	1685.8				
		53.3=18×3+.3	.5859	1706.8	
.5750*	1739.1				
		17.8			
.5692	1756.9				90.2=18×5+.2
		18.3			
.5632*	1775.2				
		35.4=18×2−.6	.5565	1797.0	
.5523*	1810.6				
		18.9			54.2=18×3+.2
.5466	1829.5				
			.5402	1851.2	
					18.0
			.5350	1869.2	

* Strong.

one frequency unit, that for set B_0 they never exceed .2, and that the wide departures in the two last intervals are to be ascribed to a slight mislocation (by two Ångstrom units) of the band .5523 which is believed to be due to a slight irregularity in the scale of the direct-reading drum of the spectrometer not adequately corrected for in the calibration.

The interval 18 which seems to be applicable to the various spectra considered in this paper, is of the same order as the intervals found to exist between neighboring components in the fluorescence of the uranyl salts. It is also incidentally almost exactly the Tanaka interval[5] for uranium as found by that investigator in his determination of the relation between the frequency interval in cathodo-luminescence and the atomic weights of the activating element.

CALCIUM FLUORIDE AS A SOLVENT

The fact that fluorspar is luminescent and often contains as activators traces of the rare earth elements such as samarium,[6] led us to try calcium fluoride as a solvent for uranium. To this end a number of procedures were used.

a. Powdered fluoride was heated upon a platinum wire to fusion, the bead thus formed was dipped into a dilute solution of uranyl chloride and again brought to the molten state. When exposed after cooling to excitation by the iron spark, by a mercury arc in quartz or by cathode bombardment, it showed a fine green luminescence.

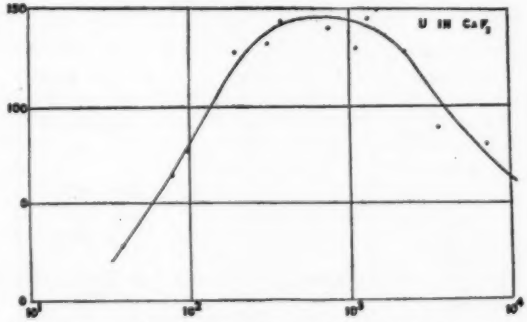


FIG. 8. *Curve for the optimum; CaF_2 as solvent.*

b. One corner of a crystal of fluorspar, nearly colorless, was moistened with the uranyl chloride solution and brought to incipient fusion in an oxy-hydrogen flame supplied with a minimum of oxygen. Under photo-excitation the fused portion glowed with the characteristic green luminescence.

c. Powdered UO_2F_2 was mixed with CaF_2 also powdered, in the desired proportions, and the mixture was heated in the oxy-hydrogen flame.

[5] T. Tanaka, J.O.S.A., *8*, p.287, 1924.

[6] See the extended investigations of Crookes, LeCoq de Boisbaudran, Urbain and others, and the recent studies by Miss Frances G. Wick, Phys. Rev., *2* . . . .

d. In attempts to avoid the great variations in brightness exhibited by beads prepared in the foregoing ways UO_2NH_4F was dissolved in water and the calcium fluoride was moistened with this solution before heating. No greater uniformity of product, however, was obtained by this process, and it was soon found that the difficulty lay in the conversion of portions of the fluoride into calcium oxide. Uranium, as opposed to other activators used with calcium fluoride, becomes inert when that solvent is converted into the oxide. This unexpected result was verified by oxidizing fluorescent preparations and thus rendering them inert and by treating inert solid solutions of uranyl fluoride in CaO with hydrofluoric acid, thus changing the oxide into the fluoride, and then applying heat treatment, whereupon they became fluorescent.

The optimum value. The difficulty just mentioned in controlling the brightness of beads of a given concentration complicates the determination of the optimum, but by giving particular attention to uniformity of heat treatment the results plotted in Fig. 8 were obtained. As in previous curves for the optimum, abscissae are on a logarithmic scale

TABLE 6. *Luminescence spectrum of uranyl fluoride in calcium fluoride at 20°C.*

Set A			Set B		
μ	$1/\mu\times10^3$	Δ	μ	$1/\mu\times10^3$	Δ
.5051	1980				
			.5076	1970	
		54=18×3			18
			.5123	1952	
.5192	1926				
		36=18×2			72=18×4
.5291*	1890				
		18	.5319	1880	
.5342	1872				18
			.5370	1862	
		36=18×2			18
			.5423	1844	
.5447	1836				18
		18	.5476*	1826	
.5500	1818				18
		18	.5531	1808	
.5555*	1800				18
		18	.5586	1790	
.5612	1782				36=18×2
			.5701	1754	

* Crest.

* Crest of U in NaF.

while ordinates are plotted on a direct scale. The maximum brightness is seen to occur with one molecule of uranyl fluoride to that of the solvent, a value between that for sodium phosphate and that for sodium fluoride.

The spectrum of uranyl fluoride in calcium fluoride presents to the eye the appearance of a single broad band rather than of a group of bands. It would not be possible to map it definitely as the previous spectra were mapped, by assigning boundaries to its group-components.

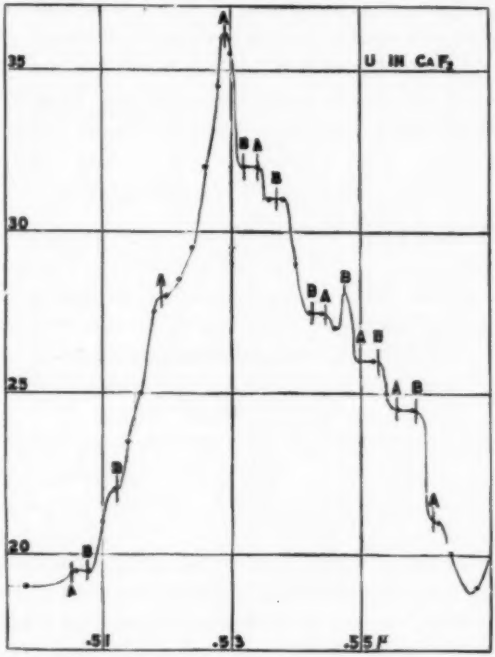


FIG. 9. *Spectrophotometric curve; $Ca\ F_2$ as solvent.*

Still there are suggestions of structure and a spectrophotometric determination shows a well developed crest (Fig. 9) and numerous semi-submerged components.

If we apply the same method as in the case of the spectrum of uranyl fluoride in sodium fluoride, basing one set upon the principal crest at .5291μ and another upon the minor crest at .5476μ it is found that the frequency interval 18 fits the curve as well as in the previous cases. (See also Table 6.) If we assume that the minor irregularities in the

curve at .5065μ, .5330μ, .5432μ, .5515μ and .5570μ represent single components, four sets will be required, but if they are taken to be doublets sets *A* and *B* suffice. The latter assumption is used in the figure and table.

After the curve in Fig. 9 had been plotted from the spectrophotometric readings and Set *A* in Table 6 had been compiled it was noted that *Set A is identical with Set* A_1 *in Table 4*; the position assigned, by inspection of the curve, to the principal crest being 90 units towards the violet from the principal crest of the curve for U in NaF (Fig. 5).

The same remark applies to the spectrum of uranyl phosphate in $NaPO_3$ (Fig. 3) where however it is Set 2, instead of Set 1, which coincides with the *A* sets of the other two solutions. It is to be inferred from this that the main crest lies at the right edge of the group band *A* at .5005μ.

SOME MISCELLANEOUS OBSERVATIONS

1. *Molecular weights of the solvents and wave length of main crests.* The color of luminescence of U in NaF is yellow, in CaF_2, $NaPO_3$, and borax, green, and in KPO_3 blue green, which suggests a shift of color with the molecular weight. Taking the three solutions for which the position of the main crest has been determined we have

Solvent	Molecular Weight	Crest (μ)
NaF	42	.5555
CaF_2	78.07	.5291
$NaPO_3$	102.4	.5008

and as will be seen from Fig. 10 nearly an inverse linear relation. In KNO_3, with a molecular weight of 118.5, the crest of the spectrum should lie at about .49μ (see the hypothetical position marked *X* upon the extrapolated curve). This would place the crest in Band *A* of Fig. 4 to the right hand of the center as there indicated, which is the probable location. Tanaka, in his paper already cited[7] noted a similar relation between the maximum of brightness in the luminescence of solid solutions of copper in various salts of calcium.

2. *Phosphorescence and Thermo-luminescence.* None of the substances considered in this paper show a noticeable afterglow at 20° or at −180° as observed without the aid of a phosphoroscope, and none of them are perceptibly thermo-luminescent. After exposure to x-rays,

[7] Tanaka, J.O.S.A., *8*, p. 294; 1924.

to which they are inert so far as any direct effect is concerned, it was found that the solutions in NaF and CaF_2 showed decided thermo-luminescence, in which respect they resemble fluorites and calcites previously studied.[8] Solutions in NaF after exposure to x-rays for one hour, showed a *bluish green* thermo-luminescence, even in the case of a bead having a proportion of $1:10^7$, when heated to an approach to a dull red. Solutions in CaF_2 gave a bright green thermo-luminescence (after x-ray treatment) in which the banded structure of the spectrum was momentarily visible. This brief glow was followed by a glow of

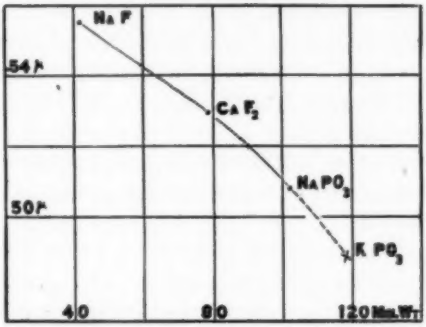


FIG. 10. *Relation between molecular weights of solvents and position of the main crests.*

slow decay, yellow or orange in color and doubtless due to traces of other activators present in the solvent as it was also obtained with beads containing no uranium. Solutions in $NaPO_3$ when exposed to x-rays acquired a *pink* body color. Their photo-luminescent properties were not perceptibly modified, but they showed *no thermo-luminescence*.

Samples made by impregnating $CaSO_4$ with traces of a uranyl salt in solution and igniting at moderate heat, were inert to photo-excitation but after exposure to x-rays for one hour there was bright green thermo-luminescence of rapid decay. This experiment was tried because it was known that thermo-luminescence could be produced when manganese was used as an activator of this solvent.

3. *Previous exposure to ultraviolet radiation* was applied to the various solutions, as a possible substitute for x-rays, but no thermo-luminescence was thus produced.

4. *Possible effect of dissolved platinum.* Since in the case of these solvents, particularly of the sodium phosphates, platinum is more or

[8] Frances G. Wick, Phys. Rev. *25*, p. 588; 1925.

less attacked, the question of the influence of dissolved platinum upon the luminescence arose and tests were made in which platinum compounds were introduced into the solutions. The results were entirely negative.

SUMMARY

1. Traces of a compound of uranium when brought by fusion into solid solution in $NaPO_3$, KPO_3, Borax, NaF, or CaF_2 render the substance luminescent under photo- or cathodo-excitation.

2. There is a definite optimum proportion for each solvent which gives the maximum brightness.

3. The spectra of these solid solutions consists of several bands each of which is made up of numerous overlapping and semi-submerged components, but the spectral structure is distinctly different from that of the uranyl salts.

4. The components may be arranged in two or more sets the frequency interval between members of a given set being constant or some exact multiple of a constant.

5. The frequency interval (18) is the same for all sets of each spectrum and for the different spectra.

6. At least one set in the spectra of preparations in which $NaPO_3$, NaF and CaF_2 respectively are the solvents is repeated in position so that these spectra may be regarded as made up chiefly of the same components and as differing only in the *relative brightness* of the components.

7. The position of the brightest component which determines what may be called the *main crest* of each spectrum, is shifted towards the violet with increase of the molecular weight of the solvent, so that the color of luminescence goes over from yellow for NaF into green for CaF_2 and $NaPO_3$ and into blue green for KPO_3.

8. The phosphorescence of these preparations is of the vanishing type.

9. They are inert under x-rays but after exposure to x-rays they become thermo-luminescent.

10. At the temperature of liquid air the spectra of solutions in NaF are resolved, those in CaF_2 partially resolved, while those in the other solvents remain unresolved.

DEPARTMENT OF PHYSICS,
CORNELL UNIVERSITY, ITHACA, NEW YORK,
OCTOBER 1925.

INTENSITIES AND REFLECTING POWERS IN THE LYMAN REGION OF THE HYDROGEN SPECTRUM

[1216-912 A U]

By A. H. Pfund

As a result of the impetus given spectroscopy by the Bohr theory much attention has been devoted to the measurement of wave length. Comparatively little, however, has been done on the subject of energy relations. In the following, some energy measurements of the unresolved spectrum of hydrogen are presented. The purpose of the work is to compare the energy carried by the Lyman series with that of the summation of all of the other series of hydrogen i.e., Balmer, Paschen,[1] Brackett,[2] etc.[3] Subsequently, the reflecting powers of materials, widely used as reflectors, are measured. The work is, largely, of a preliminary nature and paves the way for a more detailed investigation of the subject.

The general disposition of the apparatus is shown in Fig. 1. A large discharge tube having a total length of about 120 cm is attached to a bell jar so that the radiations from the horizontal portion of the discharge

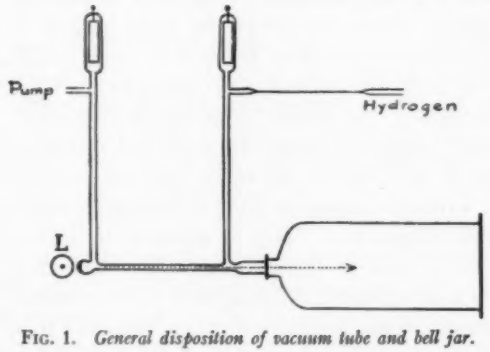


Fig. 1. *General disposition of vacuum tube and bell jar.*

tube may be taken out "end-on." The tube was usually evacuated to a pressure of 0.08 mm. A steady stream of hydrogen was allowed to enter the tube through the usual long capillary and the pump was kept

[1] Paschen, Ann. d. Phys. *27*, p. 537; 1908.
[2] Brackett, Astrophys. J l. *56*, p. 159; 1923.
[3] Pfund, J.O.S.A. & R.S.I., *9*, p. 193; 1924.

in operation continuously. Excitation of the tube was effected by means of a transformer whose 7,500 volt terminals were connected to the tube directly. The secondary current was held at 0.22 amperes.

In addition to the radiations of hydrogen, a stream of electrons, ions and molecules enters the bell jar. All of these would affect the junction of a thermocouple placed so as to receive the hydrogen radiations and would, hence, falsify the results. It was therefore necessary to resort to reflections for, a concave mirror will bring radiations to a focus but not ions and molecules. Consequently, the apparatus was arranged as is shown in Fig. 2. The radiations from the discharge tube V were received on a concave, glass mirror M_1 and were focused on one junction

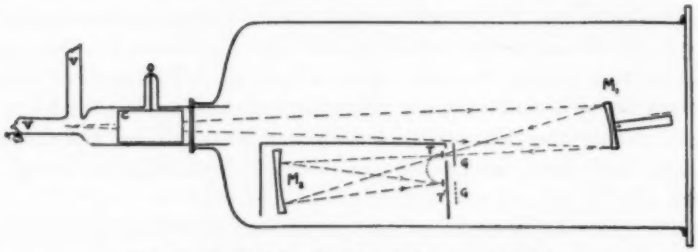


FIG. 2. *Detailed drawing of optical system in bell jar.*

of a compensating thermocouple T. In order to measure the reflecting power of glass a second mirror of the same kind of glass (spectacle crown $n=1.52$) was mounted at M_2 so that, upon rotating the thermocouple from T to T', the radiation was again focused on the same junction. The details of the mounting of the thermocouple are shown in Fig. 3. As is evident from the drawing, the thermocouple could be rotated from T to T' by means of an external magnet acting on the armature I. Proper collimation could be established through the use of a small external lamp at L (Fig. 1) whose radiations passed through the horizontal portion of the vacuum tube. The thermocouple was connected to a D'Arsonval galvanometer of high sensitivity. A plate of glass or fluorite could be inserted at G or removed to G'. This operation was likewise carried out by means of an external magnet.

Upon establishing the discharge through the tube, very large and erratic galvanometer deflections were produced. These were found to be due to a stray discharge passing from the tube to the thermocouple. Fortunately this difficulty was eliminated completely upon inserting an earthed, auxiliary electrode at C. A final and crucial test for the

existence of spurious galvanometer deflections could be carried out by deflecting the pivoted mirror M_1 (with an external magnet) so that the radiation would be thrown off the thermocouple. This test revealed that all spurious effects had been removed.

No measurements were taken until the tube had reached the "black stage"[4] i.e., until the secondary spectrum had disappeared. To be sure, an extremely feeble secondary spectrum was always present near the orifice entering the bell jar. The intensity of this radiation was, however, quite negligible in comparison with that of the brilliant Balmer lines.

This entire work is based on the tacit assumption that the intensity of the secondary spectrum is, essentially, zero and that a piece of thin glass, interposed at G (Fig. 2) will absorb the Lyman spectrum completely and, at the same time, transmit the other series of greater wave length almost entirely. The glass plate used had a thickness of 0.65 mm and was almost completely transparent from 3000A in the ultraviolet to beyond 4μ in the infrared. Not satisfied with the results obtained with the glass plate, a plate of water-white fluorite 0.85 mm thick and also a film of nitrocellulose so thin as to show first order Newton's colors were used. Briefly, all three substances yielded the same results. Since fluorite is transparent from about 1400A[5] in the ultraviolet to 9μ in the infrared, it seems rather probable that the basic assumption is tenable.

Correction for radiation from the hot walls of the tube were made as follows: the glass plate was removed and the tube was excited for four seconds whereupon the resultant galvanometer deflection d was recorded. Due to the radiations from the hot walls, the galvanometer deflection would not return to zero but would fall back to a sensibly constant value d'. The true deflection d_0 due to the hydrogen radiations was therefore placed equal to $d_0 = d - d'$. As a matter of fact, this correction amounted to less than five per cent of the total deflection. A further correction was introduced so as to allow for the failure of the thermocouple, either at T or T' (Fig. 2) to intercept all of the radiation. Use is made of the external lamp L by means of which the reflecting power of the glass mirror M_2 is determined experimentally. Since the *calculated* reflecting power is 0.043, the proper correction factor may be evaluated.

[4] Wood, Phil. Mag., *42*, p. 729; 1921.
[5] Lyman, Spectroscopy of Extreme Ultraviolet, p. 57; 1924.

ENERGY IN THE LYMAN SERIES

In order to detect, if possible, the energy in the Lyman region, it seemed desirable to accentuate these intensities as much as possible and to weaken the intensities in the spectral regions of greater wave length. From the form of the dispersion curve it was anticipated that glass,

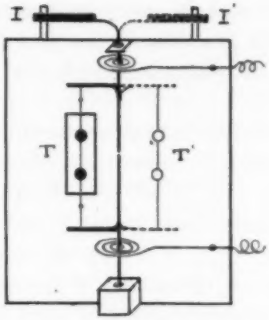


FIG. 3

with its increasing reflecting power for decreasing wave lengths, offered more promise of success than did metal mirrors. Therefore, both mirrors M_1 and M_2 were made of glass. A typical set of observations is here recorded.

Source	Galvanometer deflections			
	Reflection from M_1		Reflection from M_1 and M_2	
	Glass plate out	Glass plate in	Glass plate out	Glass plate in
Hydrogen tube	340 mm	17 mm	28.5 mm	0 mm
External lamp	325 mm	295 mm	15.0 mm	13.5 mm

These data show that the introduction of the glass plate affected the radiations from the external lamp very slightly. The radiations from the hydrogen tube, however, were cut down to five per cent of their original intensity—thus indicating that a radiation not transmitted by glass is the carrier of this energy. Since identical results were obtained when a fluorite plate was interposed, it is concluded that the Lyman series (1216-912A) is the carrier of this energy. Without going into the details of the calculations and corrections it may be stated that the reflecting power of glass in this region was found to be 0.085. It was now possible to calculate the ratio $I_L \div I_\Sigma$ where I_L = energy carried by the Lyman series of hydrogen and I_Σ = energy carried

by the Balmer, Paschen and Brackett series of H. The average of a number of measurements gives the value

$$\frac{I_L}{I_Z}=8.8$$

This means that the energy carried by the Lyman series is 8.8 as intense as that carried by *all* of the other series of hydrogen put together. If anything, this value is too low since it is more than probable that some absorption of the Lyman rays takes place as they pass from vacuum tube to thermocouple. This uncertainty is to be eliminated through the use of a fine slit between vacuum tube and bell jar, thus making it possible to maintain a high vacuum in the latter. With this very intense radiation available, energy measurements of the invididual Lyman lines are to be undertaken in the near future.

REFLECTING POWERS

Having once obtained the absolute reflecting power of glass in the Lyman region, it was comparatively simple to measure the reflecting powers of other materials in this region. The apparatus is sketched in Fig. 4. A circular metal disc B, rotatable by means of an external magnet, bore eight circular openings, 10 mm in diameter, back of which

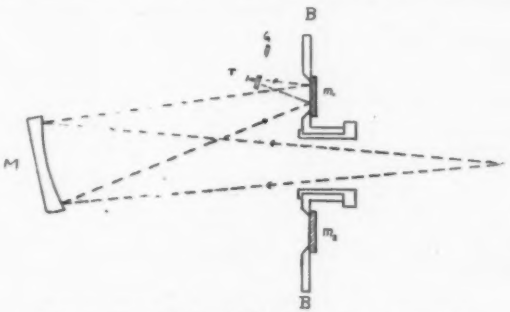


FIG. 4. *Detailed drawing of thermo-couple mounting.*

the several mirrors m_1 m_2 etc. were mounted. As before, the radiations from the vacuum tube were received on the glass mirror M_1 and, after reflection from m_1, were brought to a focus on the blackened disc of the thermocouple T. One of the eight mirrors was a piece of flat (spectacle crown) glass whose back surface was painted black. The previously determined reflecting power of crown glass served as a standard for the other mirrors. The glass plate G, previously used to eliminate the Ly-

man region, could be introduced or removed at will. Following are the results:

Mirror	Reflecting Power	Remarks
	(percent)	
Speculum	5.2	Plate for diffraction grating
Silver	5.1	Chemically deposited
Gold	6.3	Cathode layer
Platinum	8.0	Cathode layer
Quartz	13.5	Crystalline plate
Glass	8.5	Crown spectacle
Selenium*	6.5	Cathode layer
Tellurium*	7.2	Cathode layer

* Shortly after deposition, selenium and tellurium mirrors showed almost double the recorded reflecting powers. After being exposed to air for several days the mirrors lost their high reflecting power.

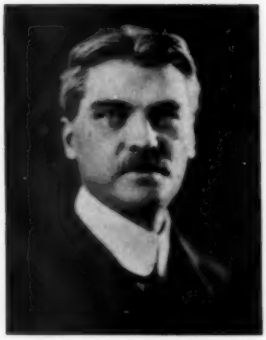
These results show that metals, as a class, reflect poorly in the Lyman region. Speculum, thus far used almost exclusively for reflection gratings, is particularly inefficient. A concave grating ruled on glass would possess not only a higher reflecting power than one made of, or, coated with metal but could be exposed to a great variety of vapors without being harmed. Of all materials studied, crystalline quartz was found to be the best. It is not improbable that the ultraviolet region of anomalous dispersion for quartz is being approached. A detailed study of this entire problem with spectral resolution, it is hoped, will yield much additional information.

JOHNS HOPKINS UNIVERSITY,
BALTIMORE, MARYLAND, NOVEMBER, 1926.

Striations in the Positive Column of a Discharge in a Rarefied Pure Gas.—To the old question as to whether striations would occur in the positive column of a perfectly pure gas, Banerji contributes from experimental work of his own the statements that striations may be obtained in pure nitrogen, and also in helium of "unquestionable" purity. "In fact, after having worked with pure H_2, He, Ne, A, N_2, O_2, Cl_2, I_2, [Banerji] came to the conclusion that striation can be produced in all pure gases." In argon he observed alternating striae showing the "blue" and the "red" spectra of argon respectively, and quite detached from one another.—[B. N. Banerji, Simla; Nature *116*, pp. 429-430; 1925.]

KARL K. DARROW

IRWIN G. PRIEST
Washington, D. C.
VICE-PRESIDENT



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OFFICERS OF THE OPTICAL SOCIETY OF AMERICA
1926-27

Tenth Annual Meeting of the Optical Society of America

MINUTES

The tenth annual meeting of the Optical Society of America was held at Cornell University, Ithaca, New York, on Thursday, Friday, and Saturday, October 29, 30, and 31, 1925. The meeting was one of the largest in the history of the Society, the attendance at the several sessions being nearly one hundred.

The annual dinner was held Thursday evening, ninety-six members and guests being present. Following the dinner short addresses were given by the retiring President, Dr. H. E. Ives, and by Professor E. M. Chamot, Professor Simon H. Gage and Professor Dayton C. Miller. The tellers (Messrs. Tuckerman, Gibson, and Wright), appointed to canvas the official ballots for the election of officers, reported that the following were elected for terms beginning January 1, 1925:

PRESIDENT.....W. E. Forsythe
VICE-PRESIDENT.....I. G. Priest
SECRETARY (five year term)..C. C. Bidwell

Members of the Executive Council:

K. T. Compton
C. E. K. Mees
P. G. Nutting
C. W. Keuffel

Among the noteworthy events of the meeting may be mentioned the following: The retiring presidential address of Dr. H. E. Ives on "Some Photographic Problems Encountered in the Transmission of Pictures by Electricity"; an invited paper by Professor E. M. Chamot of the Department of Chemistry, Cornell University, on "Chemical Microscopy: Its Aims and Possibilities"; an invited paper by Professor Simon H. Gage, Emeritus Professor of Histology and Embryology, Cornell University on "The Microscope: Its Development and Some Recent Improvements"; and an evening lecture, open to the public, by Professor Dayton C. Miller, Professor of Physics at the Case School of Applied Science, on "Contributions of Optical Measurements to Physical Theory."

On Saturday morning a business meeting was held. Professor J. P. C. Southall, Chairman of the Committee on the Helmholtz Translation, gave a report of progress, and indicated that the third volume of the translation would be ready for distribution within a few weeks.

The Executive Council reported that at its annual meeting, held October 29 and 30, the following items of business were transacted:

1. *Transfers from associate to regular membership*:

Aldrich, L. B.	Hoover, W. H.	Paul, M. Rea
Amberson, W. R.	Howe, Harley E.	Roebuck, John Ransom
Buttolph, L. J.	Kemble, Edwin C.	St. Peter, Wilfred N.
Cowan, Alfred	McDowell, Louise S.	Taylor, Lloyd W.
Friedenwald, Jonas Stein	Millar, Preston S.	Venable, William Mayo
Hamer, Richard	Miller, Dayton C.	Weigle, J. J.
Harrison, T. R.	Newcomer, H. S.	

2. Dr. Paul D. Foote was re-elected Editor-in-Chief of the JOURNAL for the term beginning January 1, 1926.

3. The following were elected associate editors for six years, beginning January 1, 1926:

Frank Allen	G. S. Fulcher
K. T. Compton	I. C. Gardner
K. K. Darrow	L. A. Jones

4. F. K. Richtmyer was appointed Secretary pro tem to act during the absence from Ithaca of Professor C. C. Bidwell, Secretary-elect.

5. It was voted that the Secretary should proceed to the publication of an up-to-date list of members of the Society.

6. The advisability of holding a mid-winter meeting jointly with the Montreal meeting of the American Physical Society was discussed, and Professor K. T. Compton was appointed to confer with the American Physical Society and to report to the Council.

7. The time and place of the next annual meeting was referred, for consideration and report, to a Committee consisting of G. W. Moffitt, Chairman and E. C. Crittenden.

Upon recommendation from the Executive Council, it was voted that a committee be appointed to consider, and report upon, the general question of the relation of Sections of the Society to the Society.

The following addresses, papers, and reports were presented during the several sessions.

ADDRESS OF WELCOME BY DR. LIVINGSTON FARRAND, PRESIDENT OF CORNELL UNIVERSITY

Radiation, Spectrometry and Miscellaneous Papers

1. H. T. Wensel and C. O. Fairchild — **Bureau of Standards**

METHODS AND COMPUTATIONS IN OPTICAL PYROMETRY.

This article collects into one paper all the important equations of optical pyrometry which at the present time can be found only by consulting many different papers. Simplified developments are given for some of the well known formulae and several entirely new relations are pointed out. It is shown, for example, that a linear relation exists between the reciprocal of the effective wave length and that of the absolute centigrade temperature, and also that the reciprocal of the mean effective wave length between two temperatures is the mean of the reciprocals of the effective wave lengths at those two temperatures.

The paper contains complete model computations for the guidance of users of pyrometers as well as tables to facilitate computation.

The present paper will appear in full in Scientific Paper of the Bureau of Standards.
(Received September 26, 1925)

2. C. O. Fairchild, W. H. Hoover, and M. F. Peters — **Bureau of Standards**

A NEW DETERMINATION OF THE MELTING POINT OF PALLADIUM.

The melting point of palladium was determined using the standard optical pyrometer of the Bureau of Standards, and metal of highest purity. Two methods were used, (1) sighting pyrometer into a black body immersed in freezing metal in a crucible, and (2) sighting into a Lummer-Kurlbaum black-body furnace during the melting of a bit of wire placed within the furnace. The latter method is shown to be less reliable than the former. The result of method (1) is 1553.5°C. This is based upon 1063°C for the melting point of gold and Wien's law in which c_2 is taken as 1.432 cm. deg. The gold used was spectroscopically pure and the palladium nearly so.

The best previous results range in value from 1550° to 1556° and the mean of these differs by less than 1° from the value reported here. Explanations are offered of some of the discrepancies appearing in earlier works.

The present paper will appear in full in Scientific Paper, Bureau of Standards.
(Received September 26, 1925)

3. **Herbert E. Ives** **Bell Telephone Laboratories**

THE LUMINOUS PROPERTIES OF THE BLACK BODY.

The latest values for the constants of the black body are used, in conjunction with the Gibson-Tyndall luminous efficiency curve of the spectrum, to compute the luminous efficiency and brightness of the black body over a large range of temperatures. The value .00161 watts per lumen is used for the least mechanical equivalent of light. The computed values agree everywhere to within one per cent with the most recent experimental values.

Bibliography:

For references covering this whole subject, see, Ives, The Photometric Scale, Jourl. Franklin Institute, July, 1919.

The present paper will appear in full in J.O.S.A. and R.S.I.

(Received September 22, 1925)

4. **Hermann Kellner and Henry F. Kurtz** **Scientific Bureau, Bausch & Lomb Optical Co.**

MODERN LABORATORY SPECTROMETERS.

Three instruments are described:

1. A precision spectrometer with 90° constant deviation prism after Abbe, objectives of 33 mm diameter, and wave length drum reading to 10 Angstrom units.

2. A chemical laboratory and students spectrometer with 90° constant deviation prism after Abbe, objectives of 22 mm diameter, and wave length drum reading to 10-25 Angstrom units.

3. A quartz monochromator with 130° constant deviation. The prism system is a modification of Young's arrangement. The wave length drum reads to 10 Angstroms in the ultraviolet.

In all three instruments an attempt is made to adapt them to their respective uses by applying good engineering principles in preference to following conventional instrument makers' design. Some details are improved adaptations of known constructions while others are new. The aims were rigidity, permanence of adjustment, protection against dust and fumes and ease of manipulation.

(Received September 25, 1925)

5. **R. A. Wetzel** **College of the City of New York**

A SIMPLE SPECTROMETER AND AN INEXPENSIVE SPECTROGRAPH FOR HIGH SCHOOL LABORATORY STUDENTS.

In an equipped secondary physics laboratory as many as twenty-four students work for three quarters of an hour upon the same problem at the same time, each with his own apparatus. The equipment usually remains set up for a week during which hundreds of students pass through the "mill" to gather what they can of laboratory method and technique.

Our twenty-four spectrometers each consist of meter-stick, slit, Meeker burner and a two-dollar Rowland grating replica (15,000 lines per inch) with which the first three digits of a sodium and lithium wave-lengths are measured subjectively.

Our twenty-four spectrographs consist of a dark box with a two-dollar replica for window at one end and a ground glass screen with milli-meter scale or a photographic plate or film at the other end. This is mounted upon a meter-stick with a focusing lens of glass or quartz. The ordinary glass lens transmits considerable of the ultraviolet. The light source may be a 1½ ampere arc with adjustable condenser and slit for emission lines, or a 10 volt 1½ ampere straight filament lamp with an absorption cell in front of it for absorption spectra.

Photographically the student may easily get for himself fifty emission lines in Cu and ten absorption lines and bands in Nd.

The Sodium emission is most easily obtained from a small piece of rock salt or piece of glass on top of the Meeker burner.

The deliquescence of lithium salts is overcome by turning out little brass cups a quarter of an inch in diameter and filling with melted lithium bromide. A hundred of these in an air tight bottle easily supplies three hundred students.

A cup on top of a Meeker burner furnishes a beautiful red flame for quite a long time.

The present paper will appear in full in J.O.S.A. and R.S.I.
(Received September 25, 1925)

6. G. S. Fulcher **Corning Glass Works**

DUNOYER MENISCUS LENSES FOR USE IN SPECTROGRAPH.

With a prism or grating of a given size, the intensity of the spectrum lines is independent of the focal length of the objective lens and varies as the square of the aperture of the camera lens, assuming no spherical aberration. The resolving power is the same for a short focus lens, except that for photographic work it is, of course, limited by the grain size of the plate. For some problems, however, a short focus camera lens free from spherical aberration would greatly reduce the exposure time needed. In 1913 Dunoyer applied Abbe's theory to design objectives of great aperture, consisting of several meniscus lenses. In going over his work I have simplified his treatment by introducing the two symmetrical variables

$$P \equiv \left(\frac{\pi}{\varphi} + \tfrac{1}{2}\right) = \left(\frac{\pi'}{\varphi} - \tfrac{1}{2}\right); \quad R \equiv (n-1)\frac{\rho}{\varphi} - \tfrac{1}{2} = \left[(n-1)\frac{\rho'}{\varphi} + \tfrac{1}{2}\right]$$

where $1/\varphi$ is the focal length, $1/\pi$ and $1/\pi'$ are distances of object and image (positive if to the left) and $1/\rho$ and $1/\rho'$ are the radii of curvature (positive if to the left). Using these variables, Dunoyer's conclusions are readily derived and extended. In particular, a telescopic quadruplet will have practically zero aberration even for large apertures if the lenses all have the same focal length and radii determined by $R = 2(n^2-1)P/(n+2)$, where P has the values 0.5, 1.5, 2.5 and 3.5 for the successive lenses, and $n = 1.5$. More accurate expressions have also been derived taking in account the thickness and separation of the lenses. The following quadruplet, consisting of ordinary spectacle lenses ($n = 1.523$) 4 cm in diam. and 2 mm thick, has a focal length of 9.47 cm (aperture $f/2.5$) and theoretically has practically no spherical aberration throughout the visible: (1) 2.5 and 0 diopters, (2) 4 and -1.5 diopters, (3) 6 and -3.5 diopters, (4) 8 and -5.5 diopters. The computed increase of focal length is .013 mm and the radius of the image of a point source is .00075 mm, only three times the theoretical resolving power. Since the aberration depends on the separation of the lenses, the final adjustment for no aberration can be made by moving the last lens. A camera with such a lens should be about 16 times as fast as a 40 cm camera. The variables defined above might be useful in other optical theories.

(Received September 26, 1925)

7. Carl W. Keuffel **Technical Department, Keuffel & Esser**

A SIMPLE SPECTROPHOTOMETER.

In this instrument a spectrometer with relatively fixed collimator, dispersion prism and telescope is used. The movement of a glass wedge (prism) longitudinally along the axis of the telescope between the objective and eye slit, causes the spectrum formed by the dispersion prism to move laterally across the slit. Thus the spectrometer acts as a monochromator and the wave-length is read on a scale attached to the telescope from an index attached to the wedge.

The sample and comparison standard form two parallel reflecting surfaces and face one another spaced 12″ or 16″ apart. A lamp with monoplane filament in line between the spaced reflecting surfaces furnishes both surfaces with normal illumination. Movement of the lamp

between these surfaces changes the intensity of the incident illumination. The light reflected at an angle of 45° from these surfaces is directed as two beams into the spectrometer and compared by means of the divided field formed by a bi-prism near the objective of the telescope. The field is matched by moving the lamp between the two reflecting surfaces, and relative brightness of the surfaces is read directly on a scale attached to the lamp. The instrument is a simple, direct reading spectro-photometer and can be manufactured at a reasonable price.

(Received September 26, 1925)

8. Charles Sheard **Mayo Clinic and Mayo Foundation**

A COMPARISON OF THE VAN DEN BERGH METHOD AND SPECTROPHOTOMETRY IN THE DETERMINATION OF BILIRUBIN.

In 1918 van den Bergh published his monograph concerned with the investigation of bile pigment in the blood and described a method for estimating bilirubin in the serum in a dilution as high as 1 mg. per liter or 1 to 1,000,000. Spectrophotometric determinations have shown that it is possible to extend this dilution to at least 1 to 50,000,000, *i.e.* to determine with fair accuracy the presence and amount of bilirubin in 1/50 to 1/100 the strength of solution which represents the limiting value of the van den Bergh method.

(Received July 23, 1925)

9. Charles Sheard **Mayo Clinic and Mayo Foundation**

SOME APPLICATIONS OF SPECTROPHOTOMETRY TO BIOLOGICAL PROBLEMS.

In this report the results of recent experimentation, jointly undertaken by Mann and Bollman of the division of experimental medicine and Sheard of the section on physics of the Mayo Clinic, and involving spectrophotometry as the method of measurement, will be presented. These investigations have dealt with the extrahepatic formation of bile and with the site of origin of bile pigment. Also, results upon spectrophotometric methods of assay of commercial insulin as undertaken by Baldes and Sheard, of the physics section, and Adams of the section on diabetes, will be given.

(Received July 23, 1925)

10. Edison Pettit **Mount Wilson Observatory**

A NEW FORM OF THERMOELECTRIC MICROPHOTOMETER.

The photometer was designed for the study of line-intensities and the minute structure of spectral lines, although it is adapted to many other problems. Light from a nitrogen-filled lamp is sent through a slit whose image is formed on the plate. From this point it is sent through a microscope objective and a second slit image is formed on the silvered square of a Hartmann cube. The light is then reflected from this square through two microscope objectives and a right-angle prism, forming a third image of the slit upon one junction of a vacuum thermocouple. By rotating the right-angle prism slightly the image may be made to move from one junction to the other, the resulting galvanometer deflections being read by telescope and scale which are a part of the instrument.

A fine wire laid over the silvered square in the Hartmann cube, which may be viewed with an eyepiece serves to mark the slit-position for setting purposes. The dimensions of the slit image on the plate may be made as small as 0.3×0.004 mm when used with plates of medium density.

Bibliography:
J.O.S.A. and R.S.I. *7*, 187-194, 1923.

(Received July 16, 1925)

11. Charles Sheard and George E. Brown **Mayo Clinic and Mayo Foundation**

SOME FURTHER STUDIES IN THE PHOTOMICROGRAPHY OF THE SKIN CAPILLARIES AND THEIR SIGNIFICANCE.

This paper is a continuation of the research work in this field as presented by Sheard at the meeting of the Optical Society of America in October, 1924. A series of slides made from the original photomicrographs will be used to demonstrate the skin capillaries in various normal and pathologic conditions. There will also be presented tables and graphs which give summaries of studies on the size, incidence and other data relative to normal capillaries, normal capillary blood flow by decades and the effects of hypertension on capillary blood flow.

(Received September 21, 1925)

12. G. S. Fulcher **Corning Glass Works**

ANALYSIS OF RECENT MEASUREMENTS OF VISCOSITY OF GLASS.

In a previous analysis of results obtained by S. English it was shown that the change in log η due to the molecular substitution of CaO, MgO, or Al_2O_3 for Na_2O in the glass $6SiO_2$, $2Na_2O$ increased linearly as the temperature decreased below a temperature T_A which seems to correspond to the devitrification temperation of the glass in each case. The slope of the curve is proportional to the amount of oxide substituted but the factor varies with the oxide, being greatest for CaO and least for Al_2O_3. More recently English has studied the effect of substituting MgO for CaO in the glass $6SiO_2$, $1.2Na_2O$, 0.8CaO. Plotting these in the same way shows that the aggregation temperature T_A decreases to a sharp minimum for $6SiO_2$, $1.2Na_2O$,0.47MgO,0.33CaO. The slope also seems to change rapidly at this composition from that characteristic of CaO to that characteristic of MgO. The results given by English for substitution of Al_2O_3 for CaO in the glass $6SiO_2$, $1.1Na_2O$, 0.9CaO, also show a minimum $1.2Na_2O$, 0.47MgO, 0.33CaO. The results given by English for substitution of Al_2O_3 for CaO in the glass $6SiO_2$, $1.1Na_2O$, 0.9CaO, also show a minimum T_A for $6SiO_2$, $1.1Na_2O$, 0.8CaO, $0.1Al_2O_3$. It is remarkable that these viscosity measurements seem to indicate the formation of molecular aggregates in glasses which are transparent and apparently homogeneous.

(Received September 26, 1925)

13. Professor E. M. Chamot **Cornell University**

CHEMICAL MICROSCOPY: ITS AIMS AND POSSIBILITIES.

(By Invitation)

Color and Colorimetry

14. Charles Bittinger (Chairman) **Duxbury, Mass.**

REPORT OF THE COMMITTEE ON COLOR TERMINOLOGY QUESTIONNAIRE.

The Committee on Color Terminology Questionnaire, appointed at the beginning of 1924, prepared, and has widely circulated the questionnaire on color terminology which was sent something over a year ago to all members of the Society. A large number of replies have been received from this questionnaire together with many interesting letters and suggestions. These replies have been classified and the results will be presented to the Society for discussion and such action as the Society may desire.

(Received September 10, 1925)

15. **Carl W. Keuffel** **Technical Dept., Keuffel & Esser Co.**

A TRICHROMATIC ADDITIVE COLORIMETER.

A Colorimeter has been developed in which the variable stimulus is produced by additively mixing the light passed through three colored glass filters by means of a fast rotating prism. Three levers, measureably control the relative amount of each component necessary to make the variable stimulus match the sample. The sample and variable stimulus are both illuminated by the same light source (a 400 watt lamp). The comparison field is formed by a Lummer Brodhun cube. The Colorimeter will be described with the aid of diagrams.

(Received September 26, 1925)

16. **Irwin G. Priest** **Bureau of Standards, Munsell Research Laboratory**

STANDARD ARTIFICIAL SUNLIGHT FOR COLORIMETRIC PURPOSES.

In 1918 (Phys. Rev. (2) *11*, p. 502) I proposed the use of the rotatory dispersion filter for obtaining artificial noon sunlight from the gas-filled tungsten lamp at 15.6 lumens per watt (color temp. = 2848°K). At that time this was a mere *apriori* proposal, untried in actual practice. Since then, the filter has been constructed as proposed and has been in satisfactory service at the Bureau of Standards for some time. It is used as an integral part of the apparatus for determining dominant wave length and purity. (Cf. J.O.S.A. & R.S.I. *8*, p. 178.)

The purposes of the present paper are: (1) To describe this actual use; (2) To communicate detailed quantitative data on the colorimetric relations between this standard and various phases of natural noon sunlight.

The filter consists of a crystalline quartz plate between "crossed nicols," the plate being 0.500 mm thick and placed so that the path of light is parallel to the optic axis. These parts are built in a cell which is inserted as a unit near the eye in the optical train of the colorimeter. The effect is that of a blue filter having a spectral transmission such that the spectral distribution of energy delivered to the observer's eye approximates very closely to average natural noon sun at Washington. The desired reproduction is much more precise than can be obtained by blue "daylight glass," dyed gelatine filters, or solutions of selective absorbents.

Data on spectral distribution have been published previously, (Phys. Rev., Fig. 1, *loc. cit.*). The following data are now presented in order to give a clear picture of the colorimetric relations between the proposed standard and various phases of natural noon sunlight. λ_c is spectral centroid in millimicrons. (For definition, see J.O.S.A. & R.S.I., 7, pp. 1188-9.) T is color temperature in degrees Kelvin. r, g, and b are trilinear coordinates. (For definitions, see J.O.S.A. & R.S.I., *9*, p. 506.) Λ is dominant wave length in millimicrons. p is purity. In the case of the Smithsonian data, λ_c, T, r, g, b, Λ and p have been computed from the original data on spectral distribution of energy (Abbot *et al*). The Bureau of Standards data on natural sunlight come directly from observations by Priest and Gibson with the leucoscope and the rotatory dispersion colorimetric photometer. Neither natural sunlight nor the proposed standard has *exactly* a Planckian distribution. The given color temperatures are the temperatures at which the Planckian radiator approaches most closely to a color match with the stimulus in question. Relative to the Planckian radiator at this temperature, the proposed standard is slightly greenish but the difference is hardly perceptible and often vanishes. r, g, b, Λ, and p are computed on the basis of the O.S.A. Colorimetry Committee's "Excitations" and "Visibility Coefficients" (J.O.S.A. & R.S.I., *6*, pp. 549-551), with the proposed standard taken as the neutral stimulus ("white").

NATURAL NOON SUN	λ_c	T	r	g	b	Λ	ρ
Ives' summary of various data on special distribution	560.72	5000	0.334	0.327	0.339	523C	−0.03
Smithsonian data on spectral distribution at Washington							
High atmospheric transmission at summer solstice	557.63	6285	.312	.325	.363	481	0.033
Av. atmospheric transmission — summer solstice	558.33	5918	.320	.330	.350	483	0.022
Av. atmospheric transmission — winter solstice	559.93	5275	.344	.343	.313	573	0.089
Low atmospheric transmission at winter solstice	561.18	4853	.358	.350	.292	578	0.17
Mean summer and winter, average transmission	559.13	5578					
Mean of extremes	559.40	5472					
O.S.A. Color. Com., Mean (J.O.S.A. & *Bureau of Standards data*							
February 20, 1920, noon (leucoscope, J.O.S.A., *4*, p. 482)	560.13	5200					
June 26, 1922, 12:30 P.M. (rot. dis. colorimeter)	559.86	5300					
January 23, 1925, 10:10 A.M. (rot. dis. colorimeter)	560.2	5175					
January 24, 1925, 10:40 A.M. (rot. dis. colorimeter)	560.5	5075					
January 24, 1925, 1:30 P.M. (rot. dis. colorimeter)	560.1	5212					
January 25, 1925, 10:40 A.M. (rot. dis. colorimeter)	561.4	4790					
PROPOSED STANDARD							
Computed from theory	559.8	5323	0.333	0.333	0.333		0.00
Experimental checks by rotary dispersion colorimeter							
For quartz plate, B. S. 31057 A	559.8	5323					
For quartz plate, B. S. 31057 D	560.1	5216					

Referring to the data of Nutting and Jones (J.O.S.A. p. 62, March, 1920) and similar unpublished data of Munsell, Gibson and Priest on sensibility to purity differences, we find that the computed value of purity (0.012) for the O.S.A. Colorimetry Committee Mean of the Smithsonian data is less than or perhaps just about equal to the purity "threshold." At 5000° the average probable error of a single observation of color temperature is about 50°. The smallest difference perceptible *with certainty* in a single observation is about 200°. Examination of the above data in connection with those published previously (Phys. Rev. *loc. cit.*) will show that the proposed standard is fairly representative of average natural noon sun; and it may be recommended as a satisfactory laboratory standard for colorimetric measurements.

Bibliography:

Abbot, *et al*: Ann. Astrop. Obs. Smith. Ins., *3*, p. 135.
Ives: Trans. I.E.S. *5*, pp. 190-208. J.F.I. *177*, pp. 471-499.
Luckiesh & Cady: Trans. I.E.S. *9*, pp. 839-864.
Priest: Phy. Rev. (2) *11*, p. 502. J.O.S.A. *5*, pp. 178-183. J.O.S.A. & R.S.I. *7*, p. 78; *7*, pp. 1175-1209; *8*, pp. 173-200; *9*, pp. 503-520.

(Received September 19, 1925)

17. **K. S. Gibson and F. K. Harris** **Bureau of Standards and Munsell Research Laboratory**

A SPECTROPHOTOMETRIC ANALYSIS OF THE LOVIBOND COLOR SYSTEM.

The Lovibond system of color grading is based on three sets of colored glasses—flashed cobalt blue, gold red, and silver yellow. The "tintometer" with these glasses is essentially a substractive colorimeter in which adjustment to match is made by steps, instead of continuously as in a wedge instrument like the Eastman Colorimeter (Jones). Each set of glasses comprises 20 "units" with numerous subdivisions. The glasses of a given set are intended to be "all of one color, but differing in depth, the divisions of difference (i.e., the units) being equal throughout. . . . . The units . . . . have also a color equivalence in relation to each other . . . . accomplished when a normal white light can be gradually absorbed to extinction without the development of any color by successive additions of an equal number of units of red, yellow and blue glass." (Advertising Pamphlet of Tintometer, Ltd.," pp. 6-7.)

The grading of these glasses as found in actual sets is not as accurate as indicated by the numbers appearing on them. A spectrophotometric analysis of these glasses is an important step in the Bureau of Standards' investigation of methods of calibrating the glasses. Spectral transmission measurements were, therefore, made on the unit glasses of the Bureau set from 1 to 20, inclusive, over a range from 380 to 750 millimicrons.

It has been found that for all wave lengths which are of importance in the determination of the color of the glasses, whether yellow, red, or blue, the following relation holds (except for the erratic variations above implied):

$$\text{Log } T = k\ N + a,$$

where T is the transmission at a given wave length, N is the Lovibond unit from 1 to 20, and k and a are constants. This is the same relation as is found with wedges if N represents the thickness of the wedge or the distance measured from the hypothetical position of zero thickness.

The transmissive data will be illustrated, including the computed values for the so-called neutral combinations (e.g., $R_{10} \times Y_{10} \times B_{10}$) which in the higher values become distinctly reddish.

Bibliography:

J. W. Lovibond: "Measurement of Light and Colour Sensations," (London, George Gill & Sons).

J. W. Lovibond: "Light and Colour Theories" (London, 1915, E. & F. N. Spon.)

Advertising Pamphlet of "Tintometer Ltd." Salisbury, Eng., March, 1912.

Will appear in full in Bur. Stand. Sci. Papers.

(Received September 15, 1925)

18. **A. E. O. Munsell and Prentice Reeves** **Munsell Research Laboratory**

VALUE SENSITIVITY AND VALUE SCALES.

The aim of this research is to determine the physical specifications (reflection power) of a neutral value* scale in which there are equidistant visual intervals between black and white. It is assumed that if the sensitivity of the eye to value differences is determined at a number of known brightnesses (or reflection powers of different gray samples), and that if a smooth curve is drawn with sensibility and reflecting power as co-ordinates, that the area under the curve represents the total sensation. This area is divided into ten equal parts and the physical specifications (in reflecting power) corresponding to each of the ten points in sensation are read from the abcissa.

Certain standard conditions were chosen for this investigation. A neutral background, approximately half way in sensation between black and white (20 percent reflection) was selected. The ideal color quality of the incident light would be that found on an overcast day (about 6000° to 7000° absolute temperature), but in this work average noon sunlight

was used (about 5200° absolute). Under the latter conditions less dense blue filters were necessary. The size of the central field was 4° solid angle since this was large enough to avoid purely foveal vision, and small enough to eliminate complications from peripheral vision. The peripheral field (the background) was as near full size as the blue glasses worn would permit.

A brief history of the early work on value sensitivity (light adapted) is given, together with suggested value scales.

A report on the initial and successive (differential) value thresholds determined is given, and a value scale for the above standard conditions is specified.

* The word "value" is used as equivalent to the word "brilliance." See J.O.S.A. & R.S.I., vol. VI., Aug. 1922, p. 534.

Bibliography:
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The present paper will appear in full in J.O.S.A. and R.S.I.

(Received September 23, 1915)

19. Deane B. Judd **Munsell Research Laboratory and Bureau of Standard**

THE COMPUTATION OF COLORIMETRIC PURITY.

Formulas for the computation of colorimetric purity from given trilinear coordinates (r, g, b) and "luminosity coefficients" (L_r, L_g, L_b) have been derived independently by H. E. Ives and I. G. Priest. It is the purpose of this paper to present:

1. The derivation of a simpler form of purity formula. This is shown to be:

$$p = \frac{B_A}{B_A + B_W}$$

where: B_A = brightness of the spectral component $= RL_r + GL_g + BL_b$

B_W = brightness of the white component $= (r-R)/(1-3r)$ or $(g-G)/(1-3g)$ or $(b-B)/(1-3b)$

R, G and B are the coordinates of the spectral color of the same dominant wave length as the color (r, g, b) whose purity (p) is being calculated.

2. A discussion of the sources of error in purity computations together with the procedure necessary for the avoidance of error.

3. The extension of the Judd formula to Ives definition of purity for purples ($p = B_A/(B_A + B_W)$; and to Troland's definition of purity for purples ($p = -B_A/B_W$).

4. An algebraic solution for the coordinates of the equal purity lines on the color triangle heretofore found by graphical methods. If x represents either r or g or b according as X represents R or G or B respectively, this solution may be expressed in the general form:

$$X = \frac{(1-p)\,B_A + pX}{3B_A(1-p) + p}$$

as before: B_A = brightness of the spectral component $= RL_r + GL_g + BL_b$

p = purity.

Bibliography:
Ives, The Transformation of Color Mixture Equations, J.F.I., 180, pp. 653-701, December 1915.
Priest, The Computation of Colorimetric Purity, J.O.S.A. & R.S.I., Vol. 9, No. 5, November 1924.

The present paper will appear in full in J.O.S.A. and R.S.I.

(Received September 26, 1925)

20. **Herbert E. Ives** — **Bell Telephone Laboratories**

RETIRING PRESIDENTIAL ADDRESS:

Some Photographic Problems Encountered in the Transmission of Pictures by Electricity.

Photography

21. **L. A. Jones** (Chairman) — **Eastman Kodak Company**

REPORT OF THE COMMITTEE ON PHOTOGRAPHIC STANDARD OF INTENSITY.

One of the questions considered by the Sixth International Photographic Congress held in Paris, July 1925, was the standardization of the procedure and determination of speed of photographic materials. In connection with this it was desirable to adopt an international unit of photographic intensity. This committee was appointed to consider this question and to make recommendations to the Paris Congress which would be representative of the consensus of the opinion of the United States relative to this subject. A report was submitted to the Congress recommending the adoption of one visual candle power of radiation having a spectral composition equivalent to that of a radiator operating at a temperature of 5000°K. The report contained detailed data and arguments in support of this recommendation. In addition to the text of the report mentioned above, the present paper includes an account of the action of the Paris Congress on this question and a criticism of this action.

The report will appear in full in J.O.S.A. and R.S.I.

(Received September 25, 1925)

22. **Clifton Tuttle** — **Research Laboratory, Eastman Kodak Company**

THE RELATION BETWEEN DIFFUSE AND SPECULAR DENSITY.

Photographic images, produced by exposure and development of photographic materials, consist of minute particles of metallic silver embedded in a matrix of transparent gelatine. Such a deposit is a semi-diffusing medium of which the effective transmission is dependent upon the characteristics of the optical system of which it is a part. If such deposits are used for the making of contact prints all of the transmitted radiation becomes effective; while if they are used in an optical system which projects images by means of lenses or mirrors, such as in projection printers, motion picture machines, stereopticons, etc., only the specularly transmitted component is utilized. The relation between values of specular and diffuse density is therefore of considerable interest from the practical as well as the theoretical standpoint.

Diffuse and specular density measurements were made on three photographic materials. Two densitometers, one of the integrating sphere type and the second of the projection type, were used. The data obtained are shown to fit an equation of the exponential type. The ratio of light scattered to the total transmitted light is a linear function of transmission for high transmission values.

The present paper will appear in full in J.O.S.A. and R.S.I.

(Received September 25, 1925)

23. **Emery Huse and Vincent C. Hall**
Communication No. 253 from the Research Laboratory, Eastman Kodak Company

ON THE RELATION BETWEEN TIME AND INTENSITY IN PHOTOGRAPHIC EXPOSURE. THIRD PAPER.

Work has been continued on the failure of the photographic reciprocity law, $E=It$. The failure of this law using Panchromatic and Orthochromatic emulsions is somewhat greater than reported previously for high speed non-color sensitive emulsions. Slow Ordinary and Lantern emulsions show very great failure and also a marked change of gamma with intensity.

In general, for fast plates the variation of density with intensity is small, optimal intensity is at a low value, and gamma is independent of intensity. For slow plates the density variation is great, optimal intensity high, and gamma drops at low intensities. As found by Kron, optimal intensity shifts to higher values with increasing development time.

Kron's usually accepted empirical law does not fit the observed data. An alternative form

$$It = \frac{I_0 t_0}{2}\left[\left(\frac{I}{I_0}\right)^{a} + \left(\frac{I}{I_0}\right)^{-a}\right]$$

has been found to fit the observed data for fast plates over a range of 1:8,000,000 in intensity and to fit the data for slow plates at high intensities. The observed failure is greater than the calculated curve indicates for these emulsions at low intensities. This equation was suggested by Kron but it did not fit his observations. The observed data thus far indicate that the dependence of gamma on intensity follows as a result of changes in the effective grain size frequency function caused by a differential failure of the reciprocity law for grains of different sizes and sensitivities.

The present paper will appear in full in J.O.S.A. and R.S.I.

(Received September 25, 1925)

24. R. B. Wilsey and H. A. Pritchard **Research Laboratory, Eastman Kodak Company**

A Comparison of X-Ray and White Light Exposures in Photographic Sensitometry.

The characteristic curve of a photographic material for x-ray exposures was found similar in form to that for white light; as a rule the x-ray curves showed a longer toe, sharper shoulder, and a higher gamma than the white light curves. Both types of exposure gave a similar convergence of the straight line portions of the characteristic curves developed for various times. X-rays and white light gave the same maximum density on the same material, this density corresponding to the total mass of silver per unit area of the original emulsion. In the region of normal exposures, the rate of development was found to increase with exposure, this effect being generally greater for x-rays than for white light, the highest development rate reached with x-rays was usually greater than for white light. Reversal due to overexposure (solarization) was found to consist of a decrease in rate of development, the reversal effect disappearing on complete development.

The differences in the forms of the x-ray and white light characteristic curves, and the differences in the progress of development of the various exposures, could not be explained by the differences in the penetration of the radiation in the emulsion layer, but must be due largely to differences in the character of the latent image.

The present paper will appear in full in J.O.S.A. and R.S.I.

(Received September 25, 1925)

25. L. A. Jones and Otto Sandvik **Communication No. 256 from the Research Laboratory, Eastman Kodak Company**

The Spectral Distribution of the Sensitivity of Photographic Materials.

A new type of automatic monochromatic sensitometer is described, the unique feature of which is a sector wheel in which the apertures are spaced spirally about the center of rotation. While this sector wheel rotates at a uniform angular velocity it is moved longitudinally so that the spirally arranged apertures travel in the proper relation to the photographic material. A cam plate attached to the shaft carrying the sector disc actuates an electromagnetic device which moves the photographic plate forward one step after exposure through the successive apertures. In this way twelve exposures increasing by consecutive powers of two are obtained.

A study of the spectral purity of a single monochromator showed that in certain parts of the spectrum the stray radiation present was about fifty per cent of the total amount. To reduce this stray radiation to a minimum, two monochromatic illuminators were used in series.

The amount of spectral energy per square centimeter necessary to produce a silver deposit of unit density under definite development conditions was determined. The maximum sensitivity was found to be in the ultraviolet.

Gamma, the slope of the straight line portion of the characteristic curve, increased towards the red end of the spectrum.

The velocity of development, calculated by the Sheppard Mees equation, has a maximum value in the ultraviolet.

The present paper will appear in full in J.O.S.A. and R.S.I.

(Received September 25, 1925)

26. M. L. Dundon, A. L. Schoen, R. M. Briggs
Communication No. 255 from the Research Laboratory, Eastman Kodak Co.

NEOCYANINE: A NEW SENSITIZER FOR THE INFRARED.

Hitherto the most efficient sensitizers for the photography of the near infrared have been dicyanine and kryptocyanine. In the course of the preparation of kryptocyanine Dr. H. T. Clarke of this laboratory noticed that the condensation gave rise to a dye much more soluble than kryptocyanine and which therefore was not separated from the solution. This dye which we have called "neocyanine" was tested as a sensitizer and found to have a broad sensitizing band extending from 700 $m\mu$ to 900 $m\mu$ with a maximum at about 830 $m\mu$.

(Received September 25, 1925)

Physical Optics

27. L. R. Ingersoll (Chairman) **University of Wisconsin**

REPORT OF THE COMMITTEE ON PHYSICAL OPTICS.

A summary of recent developments.

28. Hillel Poritsky (Introduced by F. K. Richtmyer) **Cornell University**

FARADAY EFFECT IN SPUTTERED IRON FILMS.

Iron films, sputtered in hydrogen at 50°C, exhibit a marked change in their Faraday effect (rotation of plane polarized light in magnetic field) after having been heated to 250° for an hour or two in an atmosphere of hydrogen. Before heating the rotation is positive in the red, negative in the blue, changing sign at about $\lambda = 540$, and reaches saturation in a field of about 6000 gauss. After heating the rotation increases and becomes positive for the whole spectrum. It is now linear with the magnetic field, at least up to strengths of 8000 gauss. The electrical resistance of the films permanently decreases with the heat treatment. They also become more opaque, the absorption increasing as much as five fold. The films appear to exhibit a small natural rotation which may be destroyed by heating.

(Received September 26, 1925)

29. Herbert E. Ives and A. L. Johnsrud **Bell Telephone Laboratories**

ELECTRICAL AND PHOTOELECTRIC PROPERTIES OF THIN FILMS OF RUBIDIUM ON GLASS.

Films which spontaneously deposit on glass surfaces in a highly exhausted cell containing rubidium, are electrically conducting, and photoelectrically active. A study of the photoelectric properties of a rubidium coated plane glass surface shows the normal and selective effects less well differentiated than for the similar coatings which form on metal plates. A rubidium film formed on the inside of a glass cylinder is found to exhibit, in the dark, a pure ohmic resistance. This decreases under illumination in a manner which appears to be explained as due to the liberation of photoelectrons which under a potential gradiant form an added current along the tube.

Bibliography:

Ives, Photoelectric Properties of Thin Films of Alkali Metals, Astrophysical Journal, November, 1924.

The present paper will appear in full in Astrophysical Journal.

(Received September 22, 1925)

30. F. L. Mohler, Paul D. Foote and R. L. Chenault **Bureau of Standards**

PHOTO-IONIZATION AND RELATIVE ABSORPTION PROBABILITIES OF CAESIUM VAPOR.

The method employed for the measurement of the photoelectric effect in caesium vapor as described in Phys. Rev. *26*, p. 195, 1925, depends upon the partial neutralization of the negative space charge around a hot wire cathode by the ions produced by radiation. The change in thermionic current, upon illumination, per unit intensity at different frequencies, under specified conditions for operation, gives relative values of the Einstein probability coefficient B_ν. This absorption probability for a caesium atom for wave lengths shorter than the $1s$ limit λ3184 decreases much more rapidly with decreasing wave length than follows from the λ^3 law of Milne or the λ^4 law of Kramers. The theory of Becker is in good agreement with the data in the range λ3050-2700, while a simple empirical exponential law represents the observations throughout the observed range λ3184-2600. Appreciable ionization at wave lengths longer than the limit is produced only at the principal series lines. The resolved effect of the individual line was measurable from $1s-4p$ to $1s-9p$. The ionization is the result of line absorption which produces excited atoms which are ionized by thermal collision. The theory of the phenomenon agrees with the observational data.

Bibliography:

Foote and Mohler, "Origin of Spectra" Chap. 10. Phys. Rev. 26, pp. 195-207, 1925. Series of papers by Harrison in Phys. Rev. 1925.

(Received September 26, 1925)

31. A. Ellett, Paul D. Foote, F. L. Mohler

POLARIZATION OF RADIATION EXCITED BY ELECTRON IMPACT.

Polarization following electron impact.—If an unidirectional beam of electrons, of velocity slightly in excess of the resonance potential, is projected through a vapor at a very low pressure so that the effects due to atomic collision and resonance are negligible, and in the absence of an applied field and resulting Larmor precession, there is reason to suspect that the radiation emitted perpendicular to the electron beam should be partially polarized, especially for lines corresponding to $\Delta j=1$.

Polarization in mercury and sodium vapors.—Experiment showed a polarization of about 30 per cent for λ2537 with the greatest intensity of the electrical vibration having a direction perpendicular to the electron beam. No polarization was detected for the unresolved sodium D-lines confirming the recent observation of Kossel and Gerthsen.

Polarization in mercury with field of 3 gauss.—A field parallel to the electron beam produced no effect. With the field perpendicular to the beam the radiation along the field was unpolarized while that perpendicular to the field was reduced in polarization to 13 per cent. These results suggest that the atom radiates with the same distribution of polarization and intensity as in zero field but with the atom rotated through an angle determined by the time τ of excitation and the precessional velocity.

(Received September 26, 1925)

32. A. H. Pfund **Johns Hopkins University**

INTENSITIES AND REFLECTING POWERS IN THE LYMAN REGION OF THE SPECTRUM OF HYDROGEN.

As a result of the impetus given spectroscopy by the Bohr theory, much work has been done on the wave-lengths of spectrum lines. Little is known, however, about the relative intensities. In the following, an attempt is made to compare the integrated intensities of lines in the Lyman series of hydrogen with the summation of all the other series of hydrogen.

The radiation, taken out "end-on" from a powerful hydrogen tube, is focused by a concave mirror on one junction of a compensating thermocouple. By introducing a thin piece of microscope cover-glass into the path of the beam, only the Lyman series is absorbed entirely while all other radiations are transmitted. By allowing the radiations to fall on a second concave-mirror, it is possible to measure the reflecting powers of various surfaces. The entire apparatus is evacuated—all necessary operations being carried out by means of external magnets.

The results obtained show that the intensity carried by the Lyman series is several times greater than that carried by all the other hydrogen series (Balmer, Paschen, etc.) put together. It is furthermore found that glass and quartz are better reflectors in the Lyman region than are the metals.

The present paper will appear in full in J.O.S.A. and R.S.I.

(Received September 25, 1925)

33. William Mayo Venable **Blaw-Knox Company, Pittsburgh**

A CLASSIFICATION OF THE LINES OF THE SECONDARY SPECTRUM OF HYDROGEN.

Over 400 of the 1130 lines of the secondary spectrum of Hydrogen measured by Merton and Barratt are arranged in groups, the members of which differ from one another in frequency by the same amounts as neighboring lines of the Lyman series.

Bibliography:

"On the Spectrum of Hydrogen" by Dr. T. R. Merton and Mr. S. Barratt, Phil. Trans. Roy. Soc. 222, A (1921-22).

(Received September 9, 1925)

34. E. L. Nichols and Mabel K. Slattery **Cornell University**

URANIUM AS AN ACTIVATOR OF LUMINESCENCE.

(1) *In Sodium Fluoride*, impregnated with traces of a salt of uranium and fused, the fluorescence at room temperature is a vivid canary yellow, very brilliant under photo-or cathodo excitation. The optimum brightness is at about one molecule of UO_2Fl_2 to 2000 molecules of NaF. Preparations containing one molecule to 10 million of the solvent are still brightly fluorescent. The spectrum at room temperature consists of several rather broad bands, comparable to those in the luminescence spectra of the uranyl salts. These at $-190°C$ resolve into two sets of line like bands with the Tanaka interval for uranium (17.8).

(2) *In Calcium Fluoride*, the fluorescence is green and the optimum occurs at the ratio 1:500. The bands are partly resolved at $-190°C$. Luminescence is destroyed by heating to a temperature at which the CaF_2 changes to CaO.

(3) *In borax*, when heated to a temperature short of fusion the fluorescence is green and the spectrum has three broad bands (crests at about .500, .525, .550μ). Further heating (to formation of a bead) gives a single broader band by merging of these. There is no resolution at −190°C.

(4) *In sodium phosphate* (from microcosmic salt), the fluorescence is green, with a three banded spectrum; optimum ratio about 1:500. In liquid air the resolution is incomplete.

(5) *In potassium phosphate*, the fluorescence is greenish blue; spectrum broadly banded.

(6) *In calcium phosphate*, sulphate and oxide, as in most other solvents commonly used, uranium appears to be inert.

(7) In solvents containing water of constitution (3, 4 and 5) luminescence is destroyed by heat treatment which expels the water and is restored by dissolving and reheating.

Bibliography:
1) Urbain: Comptes Reudus, CXLVII, p. 1472.
2) Nichols and Howes: Carnegie Institution, Publication 298.
3) T. Tanaka: J.O.S.A. and R.S.I., VIII, p. 287.

(Received August 29, 1925)

35. P. V. Wells **Laboratory of the Prudential Insurance Company of America**

NOTE ON TECHNIQUE OF MAKING TURBID WEDGES.

In the effort to obtain a satisfactory turbid wedge, a simple technique was hit upon which will interest others in the study of diffusing media. A very fine white pigment suspended in a cellulose nitrate base, such as the new enamels now on the market, is diluted with clear pyroxylin solution to the desired consistency and concentration of pigment. This suspension is then cast as a wedge on plate glass, and stripped from the glass when dry. In this form a direct reading scale can be ruled upon it. Such wedges have the advantages of permanency and reproducibility at a trifling expense.

On visiting the Redpath Laboratory of the Du Pont-Pathe Film Manufacturing Company at Parlin, I found Mr. Conklin had independently invented pyroxylin turbid wedges. The wedges of bismuth oxychloride suspended in gelatin, used by the former Director of Redpath Laboratory, Mr. Renwick, were not satisfactory because they darkened on exposure to light. I wish to thank Dr. Sease, the present Director, and also Mr. Class, Chemist of the Pittsburgh Plate Glass Company, for kindly supplying me with the pyroxylin solutions required for casting the wedges.

(Received September 25, 1925)

* * *

36. L. B. Tuckerman **Bureau of Standards**

AN ILLUSION DUE TO PATTERN INTERFERENCE.

When a carbon copy of a typewritten letter is placed over the original in register and then twisted slightly, concentric circles are seen. Although this appearance must have been seen many times, no published account has been found. Similar effects occurring elsewhere are discussed.

(Received September 25, 1925)

37. Professor Simon H. Gage **Cornell University**

THE MICROSCOPE: ITS DEVELOPMENT AND SOME RECENT IMPROVEMENTS.

(By Invitation)

Geometrical Optics

38. **W. B. Rayton** (Chairman) **Bausch and Lomb Optical Company**

REPORT OF THE COMMITTEE ON PROGRESS IN GEOMETRICAL OPTICS.

A summary of recent developments.

(Received September 23, 1915)

39. **L. V. Foster** **Scientific Bureau, Bausch & Lomb Optical Company**

DIFFRACTION GRATING IMAGES AND INTERFERENCE FIGURE IMAGES AS FORMED BY A MICROSCOPE OBJECTIVE.

A discussion of a paper on "The Influence of Some Aberrations of a Microscope Objective on the Images of Diffraction Gratings," by Albert Driesen, published in Zeitschrift für Physik, October 12, 1923, illustrated by a series of photographs taken by Albert Driesen and another series taken by the author.

(Received September 25, 1925)

40. **L. V. Foster** **Scientific Bureau, Bausch & Lomb Optical Company**

ASPHERIC ENLARGING CONDENSERS.

The enlargement of photographic negatives above the 8×10 size is uncommon, namely, because of the lack of enlarging condensers sufficiently well corrected to cover the field. The problem involved in enlarging of large negatives will be treated. The author will describe two new condensers one designed to enlarge 8×10 negatives, the other to enlarge 18×18 negatives.

(Received September 25, 1925)

41. **G. W. Moffitt** **Optical Laboratory, Frankford Arsenal**

THE VERGENCY EFFECT ON SPHERICAL ABERRATION AS A FUNCTION OF THE PARAMETERS IN CERTAIN CLASSES OF TELESCOPE OBJECTIVES.

Telescope objectives of the crown-leading cemented type have been found to differ considerably in the variation of spherical aberration with change in object distance. To obtain more data on this subject several series of objectives have been studied. The results indicate that certain series of objectives corrected for infinite object distance may show over-correction, while others may show under-correction. By choice of glasses and shape of objective it is possible to obtain an intermediate series for which the correction will be good over quite an extended range of object distance. The function is not a linear one, however, so that it is not possible to eliminate the vergency effect on spherical aberration completely in the type of objective considered.

The coma-free series was found to develop considerable under-correction as the object approached the lens, but the curve is practically parallel to the line of zero aberration for object distance infinity. The series having least vergency effect has a moderate amount of positive coma.

The application of these results in the designing of such devices as laboratory telescopes makes it possible to provide instruments well corrected for spherical aberration for any object distance from infinity to two or three times the equivalent focal length of the objective.

In general, the results would apply in the designing of any system in which one or more cemented pairs must work under widely varying vergency conditions.

Bibliography:

J. P. C. Southall: Principles and Methods of Geometrical Optics, p. 394.

H. D. Taylor: A System of Applied Optics, p. 218.

G. W. Moffitt: J.O.S.A. & R.S.I., 11, 2, 1925.

G. W. Moffitt & O. K. Kaspereit: J.O.S.A. & R.S.I., 11, 3, 1925.

The present paper will appear in full in J.O.S.A. and R.S.I.

(Received September 9, 1925)

42. I. C. Gardner **Bureau of Standards**

AN OPTICAL SYSTEM FOR READING ANGULAR DEFLECTION OF A MIRROR.

With the usual lens, mirror and scale method of reading deflections, the indicated value is proportional to the tangent of the angle of deflection. In many instruments, for example in extensometers, in which the motion is communicated to the mirror by the rolling of axis of mirror or by a pinion and geared sector a deflection proportional to the angle of deflection is desirable. This is particularly desirable if deflection is registered on a moving photographic film as it gives an equicrescent scale in each direction. A simple two lens system which can be satisfactorily made on standard spectacle tools has been designed which introduces distortion sufficient to give desired relation between deflection and indicated value and at the same time gives notable flattening of field thus permitting the photographic registry of very large deflections. Other simple relations between deflection and indicated value may be secured by redesign of the projecting system.

(Received September 25, 1925)

43. G. W. Moffitt **Optical Laboratory, Frankford Arsenal**

A SIMPLE METHOD FOR OBTAINING OPTICAL CONTACT.

It seems to be a common experience that there is trouble whenever an attempt is made to put polished pieces of glass together in optical contact. It is practically impossible to get the surfaces clean and dry without electrifying them. Dust is immediately attracted. Of course, the charges could be neutralized in a flame but the dust would still be there. Sliding the blocks together will usually dislodge the larger particles but cannot be relied upon to remove the smaller ones. There is also danger of scratching.

This need for a dependable method led to an attempt to improve the technique. After some study and a little experimentation it was found that well cleaned blocks brought together with small jets of distilled water playing on the surfaces could be kept free from particles of matter that would prevent the close contact of the pieces. The water film thus trapped was absorbed in the course of a few hours—sometimes much more quickly. The glass used was a borosilicate crown. The blocks were held together under moderate pressure in a suitable clamp during the absorption period.

Samples will be shown.

(Received September 9, 1925)

Physiological Optics

44. A. Q. Tool, L. W. Tilton and E. E. Hill **Bureau of Standards**

REGARDING THE HEAT TREATMENTS OF GLASS AND ITS REFRACTIVITY AND DENSITY.

Aside from the fact that it has been long known that the refractivity and density as well as certain other properties of glass depend to some extent upon the degree of annealing or chilling it has received, there is very little available knowledge of the actual relationships existing between the mode of treatment and the resultant changes in these properties. From the experiments so far completed, the following points now seem apparent.

1. The refractivity and density usually increase as the annealing temperature is lowered provided the annealing period is made long enough to establish equilibrium.

2. The annealing period establishing equilibrium increases exponentially as the annealing temperature is lowered.

3. When a glass is held at any constant annealing temperature the rate of approach as equilibrium is neared decreases exponentially.

4. Reannealing at a higher temperature after equilibrium has been established at a lower one practically restores both the index and density to the values normally corresponding to this higher temperature.

5. The equilibrium values for both the refractivity and density can be determined at various annealing temperatures throughout a range exceeding 100°C, and it appears that in general they continue to increase as stated above for temperatures below this range of practical investigation although observation then becomes difficult because of the slow rate of change.

6. In all these respects the changes in the refractivity and density are subject to much the same conditions as the changes in the magnitude of the endothermic effect observed on heating.

For a medium flint glass on which the most data have been obtained, the increase in the refractivity for the D line approximates 0.000023 and in the density 0.00016 per degree centigrade decrease in the effective annealing temperature. The possible error in these values approximates 1 in the last significant figure. In the range between 370 and 440°C, at least, the rate of change is practically constant. Corresponding to an effective annealing temperature of 404 ± 5°C for this glass, the density is about 3.3486 and the refractive index approximates 1.59000 at room temperature. With a soda-lime glass having a refractive index about 1.52020 for an effective annealing temperature approximately 525°C, the estimated increase in the refractivity per degree decrease in the equilibrium temperature is about 0.000027.

From the data so far obtained on other types of glass, it appears that larger increases per degree may be expected in some cases while in others they may be smaller. It is also probable that in certain cases the changes in both the density and refractivity will not so closely approximate a linear function of the change in the equilibrium temperature. Furthermore it seems that with some glasses the previous history will affect these equilibrium values for certain annealing temperatures.

When the equilibrium values for both the density and refractivity are finally obtained with sufficient accuracy for a considerable range of annealing temperatures, it will be interesting to use such values in the various formulae relating these properties. So far the data indicate that Newton's relation $\frac{n^2-1}{d}=c$ is the most satisfactory. In this regard, however, it is possible that the conditions causing these changes are such that none of these relations will apply.

Bibliography:
Twyman and Simeon, Jour. Soc. Glass Tech., 7, 199; 1923.
Lebedeff, Trans. Opt. Inst. Petrograd, 2, 1; 1921.
Foussereau, Journ. de Phys., 2, 262; 1883.

(Received September 26, 1925)

45. **Jonas S. Friedenwald, M.D.** **Department of Ophthalmology, Johns Hopkins Medical School**

THE DISTRIBUTION OF LIGHT INTENSITY IN ASTIGMATIC IMAGES WITH SPECIAL REFERENCE TO THE SENSITIVITY OF TEST CHARTS USED IN REFRACTION.

In an effort to determine the relative sensitivity of the different test charts used in the measurement of astigmatism of the human eye, a study was made of the distribution of light intensity in astigmatic images. The method used is analogous to that of Helmholtz in determining the distribution of light intensity in blur circles due to the chromatic aberration of the eye. By a simple geometrical construction based on first order theory the distribution of light intensity in a focal line of the astigmatic image of a point source was determined and was found to be expressed by the following formula:

$$I=2aH\sqrt{r^2-x^2}$$

In which I represents the intensity at a given point in the focal line, x the distance of this point from the mid-point of the focal line, r one-half the length of the focal line, and a and H are constants related to the focal lengths of the optical system and the intensity of illumination of the exit pupil.

By integration of this formula between the proper limits formulas are developed for the distribution of light intensity at the edge of an image of a uniformly illuminated area and also for the image of a narrow line. By applying these formulas to the cases of various astigmatic dials it is possible to represent graphically the distribution in light intensity in the images of the blurred elements of the dials when seen by an eye with a given amount of astigmatism, and pupillary diameter and at a given distance from the chart.

(Received September 25, 1925)

46. L. L. Holladay (Introduced by F. K. Richtmyer) Lighting Research Laboratory, National Lamp Works of General Electric Company

THE FUNDAMENTALS OF GLARE AND VISIBILITY.

A résumé is presented of the results obtained in an extensive research into the many ways in which glare affects visibility.

Visibility was studied chiefly by the method of least perceptible contrasts of brightnesses. Results are presented showing the influence of adaptation and of form and size of test-object upon contrast sensitivity.

The results of the investigation show that the least perceptible brightness-difference between an object and its background increases directly with the illumination at the eye from the dazzle-source; varies approximately inversely with the square of the angle which the glare-source makes with the line of vision; and is practically independent of the brightness, size, type, distance, etc., of the dazzle-source.

Considerable study has been given to the variations of the pupil under steady, fluctuating, and glaring lights and of their influence upon vision. Results of investigations upon irradiation, after-images, blinding-glare and light-shocks are also presented.

(Received September 25, 1925)

47. L. A. Jones and E. M. Lowry Communication No. 254 from the Research Laboratory, Eastman Kodak Company

RETINAL SENSIBILITY TO SATURATION DIFFERENCES.

Of the three attributes of color, brilliance, hue, and saturation, the latter has probably been accorded the least attention. The present work was undertaken for the purpose of obtaining specific data on this subject. Using a modified Nutting Colorimeter the sensibility of the eye to saturation differences was determined for the following colors: blue, blue-green, yellow, orange, and red. The number of equal sensation steps was found to vary for different of the eye to purity differences was determined for the following colors: blue, blue-green, yellow, orange, and red. The number of just noticeable differences, expressed in terms of purity, between the two extremes (zero and one hundred per cent purity) was found to vary for the different colors. Saturation scales were constructed by plotting per cent purity readings against equal ordinate increments. Illustrative data will be presented and discussed.

The present paper will appear in full in J.O.S.A. and R.S.I.

(Received September 25, 1925)

48. William Mayo Venable Blaw-Knox Company, Pittsburgh

THE STIMULI FOR THE VISUAL SENSATIONS.

This paper extends the investigation of changes in energy levels in the Visual Purple associated with the visual stimuli reported in a former paper entitled "The Quantum Theory and the Stimuli for the Visual Sensations," and shows that the analysis is confirmed by measurements of hue sensibility published by Nutting.

Bibliography:

"Color and Luminosity"—Venable, Am. Journ. Phys. Opt., Jan. & April, 1924.

"The Quantum Theory and the Stimuli for the Visual Sensations"—Venable—Am. Journ. Phys. Opt., July, 1925.

"The Reactions of the Retina to Light"—P. G. Nutting—Am. Journ. Phys. Opt., April, 1920.

The present paper will appear in full in Am. Journ. Phys. Opt.

(Received September 9, 1925)

49. Frank Allen **University of Manitoba**

THE VARIATION OF VISUAL SENSORY REFLEX ACTION WITH INTENSITY OF STIMULATION

In a former paper on Reflex Visual Sensations, sensory reflex actions at very high intensities of stimulation were studied. In the present research these actions have been investigated for medium and low intensities. To connect these with other phenomena, curves like those obtained by Porter, with white light, and Ives, with spectral colors, were obtained by using the spectrum of a 200 watt incandescent lamp. These curves were believed to consist of only two straight lines with an abrupt change of slope at low intensities. The lower branch was supposed to represent rod vision, and the upper, cone. It is now found that the graphs consist of from three to five branches. Stimulation with intensities represented by the lowest branches causes depression of sensitiveness; with the next two, enhancement of sensitiveness; with the fourth, enhancement of the sensation corresponding to the color of the stimulus, and depression of the remainder; with the fifth, the reverse of the fourth. The change in slope is due to a change in the ratio of the reflex depressing and enhancing nervous actions. This explains such phenomena as the Fechner Paradox, and elucidates all sensory activities.

Bibliography:

J.O.S.A. and R.S.I., Vol. VII, 1923, p. 583.

The present paper will appear in full in J.O.S.A. and R.S.I.

50. H. M. Johnson **Mellon Institute of Industrial Research**

RETINAL EXCITATION BY MEANS OF NEURAL DRAINAGE.

That a receptor which is not directly stimulated may be excited through drainage of neural flux from it into an active neural pathway, is indicated by the following observations: (1) G. H. Meyer and others report complementary after-images of *imagined* objects. (2) Titchener showed that a colored pattern, imaged on one retina only, aroused a similar, though not quite identical, process in the corresponding portion of the other retina, the two processes not always synchronizing. The after-image processes were likewise similar. (He argued against correspondence of receptors, but his results best support that interpretation.) The writer, by means of a very simple apparatus and method, obtained evidence confirming Titchener's, on 12 out of 30 observers. (3) Dunlap showed that local adaptation to an image falling on a restricted portion of one retina only, was aroused in the corresponding portion of the other retina also. (4) Frank Allen and his collaborators showed that if one eye is overstimulated by monochromatic light, measurements made with the other yield results which are such as if it carried an after-image of the fatiguing light. (5) Lashley showed that rats, having one eye permanently blindfolded while learning a discriminative response, transferred the training, without disturbance, to the other eye when the bandage was transferred, although the main neural path originally used had been ablated.

The present paper postulates a mechanism by means of which excitation by drainage can occur; and attempts, in terms of the concepts of modern physical chemistry, to describe the conditions of its occurrence.

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F. Allen, J.O.S.A. and R.S.I., 1923, et seq.

K. Dunlap, Am. Journ. Physiol., 1921.

W. James, Principles of Psychology, ii, 66 ff; 580-592.

K. S. Lashley, Psy. Rev., 1924.

E. B. Titchener, Philos. Studien, 1893, viii.

The present paper will appear in full in Journal of Comparative Psychology entitled "An essay toward a simpler principle of explanation of rational and imaginative behavior and of learning."

(Received September 16, 1925)

51. Dr. Christine Ladd-Franklin **Columbia University**

THE BLUE ARCS OF THE RETINA: "SEEING YOUR OWN NERVE CURRENTS."

If in an otherwise dark room you look at a vertical strip of bright red light you will see proceeding from it on both sides two rather large luminous arcs. The color of these arcs is a slightly reddish blue; it is not the color of the rod-pigment (the so-called visual "purple"), which is a slightly bluish red. They proceed from the fixation point, the fovea, and meet each other, nearly, at a point whose distance from the fovea, in angular measurements, is just the same as the distance from the fovea to the blind spot. They are somewhat elliptical in shape, —more exactly, they are pear-shaped, approaching more nearly towards each other at the papilla than at the fovea. The right-hand pair of arcs is seen by the right eye, the left-hand pair by the left eye; which means, of course, that they are seen by the nasal half of each eye. By moving the fixation point the two arcs on either side may be made to approach each other until they coalesce in a horizontal band, or to retreat from each other until they are far enough apart to form together something like a circle. All these marks together are, of course, sufficient to show that we are here seeing, as an entoptic phenomenon, the optic fibres that are carrying the red-light stimulus from the fovea to the exit point of the optic nerve. Dr. Amberson, who has just written an important paper on these Blue Arcs, shows that the explanations of them hitherto given are untenable. His own explanation, however, is also, from simple physiological considerations, quite impossible. It will be shown that they are, beyond question, due to a bio-luminescence of the red-stimulus conducting fibers—a property of conducting nerve fibres that they have hitherto not been known to possess.

* W. R. Amberson, Amer. Jour. Physiol., 1924.

(Received September 26, 1925)

52. W. W. Coblentz, C. W. Hughes **Bureau of Standards**

THE SPECTRAL ENERGY DISTRIBUTION OF THE LIGHT EMITTED BY SOME PLANTS AND ANIMALS.

The physical characteristics and the chemical processes underlying bioluminescence, is practically an unexplored subject.

The present investigation is a continuation of previous work[1] and deals principally with a luminescent fungus (Agaricus melleus), found in decaying wood, which emits a faintly tinged, greenish or yellowish-white light, popularly known as "fox-fire"; also a luminous crustacean (Cypridina) from Prof. E. N. Harvey[2] in the form of a dry powder which emits an intense bluish light when moistened with water.

The spectrum was photographed[1] on a panchromatic plate, requiring an exposure of an hour for the crustacean and from 30 to 71 hours, with frequent renewal of fresh material in order to obtain a good spectrogram of the luminescent fungus.

The spectral energy distribution of the luminescent fungus is long, extending from about 430 to 670 mμ with a maximum in the yellow-green. The presence of the blue and the red rays causes the whitish color. The spectrum of the crustacean is short, extending from about 420 to 550 mμ with the maximum emission in the blue-green. The spectrum of the firefly (Photinus pyralis) is short, extending from 510 mμ to 670 mμ with a maximum in the yellow. In the previous paper[1] it was shown that the light of various species of fireflies differs greatly in spectral energy distribution; and that the wave length range of this luminescence does not extend as far into the violet nor into the red to which the eye is sensitive. The results of the present investigation are in agreement with the previous work showing that the color of the light is not a subjective phenomenon, due to the Purkinje effect and to the low intensity of the light, but is owing to an actual difference in the spectral composition of the light emitted.

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[1] A Physical Study of the Firefly, by W. W. Coblentz, Publ. No. 164, Carnegie Institute of Washington, 1912.

[2] The Nature of Animal Light, E. Newton Harvey, Lippincotts, 1920.

(Received September 21, 1925.)

F. K. RICHTMEYER,
SECRETARY

INSTRUMENT SECTION

WIRE AND RIBBON WOUND RESISTANCE FURNACES*

By Charles C. Bidwell

There are two fundamental factors which determine the design and construction of electric resistance furnaces, namely, the temperature range through which the furnace is to be operated, and the temperature distribution required within the heated chamber. The factor of temperature range will largely determine the choice of resistor, refractory, and of the material and extent of the thermal insulation. The factor of temperature distribution will determine the shape of the furnace, the manner of winding the heating element and of placing the thermal insulation.

Resistors. The heating elements most generally used for lower temperature ranges, i.e., below 1000°C, are the alloys "nichrome" (a copper nickel alloy), made by the Driver Harris Co. of Newark, N. J., (apparently no longer on the market), and "chromel," grades *A* and *B*, nickel-chromium alloys made by The Hoskins Mfg. Co. of Detroit, Mich. "Chromel *A*" contains 80 per cent nickel, 20 per cent chromium. "Chromel *B*" besides nickel and chromium contains a large percentage of iron. "Nichrome" and "Chromel *A*" are particularly resistant to oxidation, holding up well even under prolonged heating at 1000°C. "Chromel *A*" has a resistance about ten times that of platinum and melts at 1385°C. Temperatures as high as 1100°C or even 1200°C may be attained with either "Chromel *A*" or "nichrome" but the life of the resistor is shortened by exposure to these temperatures. The freedom from iron impurity of these materials seems to be the secret of their resistance to oxidation. "Chromel *B*" cannot be safely used above a dull red (600°C). These alloys, probably because of the action of hydrogen on nickel do not stand up well in a reducing atmosphere. A nitrogen atmosphere probably would be advantageous. Pure nickel makes an excellent resistor, good for prolonged operation at 1000°C. 1200°C may

* One of a series of reports prepared at the request of the Committee on Research Methods and Technique appointed by the Division of Physical Sciences of the National Research Council. It is the purpose of these reports to present in brief outline a summary, more or less critical, of the methods which may be employed in various kinds of physical measurements. See editorial this Journal *9*, p. 410; 1924.

be safely attained with about the same satisfaction as regards life as with "nichrome" or "chromel *A*." The freedom of the nickel from iron impurity is likewise an essential factor in its resistance to oxidation.

The above alloys as well as pure nickel and platinum can be obtained in either wire or ribbon form. Whether in wire or ribbon form, they may be directly wound on the furnace core. With equal cross-section the resistor in ribbon form has greater covering capacity than wire. This means a saving of material which in the case of platinum is an important item. There is no gain in thermal efficiency, i.e., a higher core temperature cannot be obtained with ribbon for a given energy input. The spiral resistor is the standard form for the base metal heaters. The wire is first closely wound on a mandrel in the form of a spiral of about 1/4 inch diameter and this spiral wound on a grooved furnace core and slightly stretched out during the winding. Most furnaces on the market have this type of winding. As renewals are required from time to time the winding should not be covered with cement which would have to be chipped off, endangering the core.

On account of its freedom from oxidation and high melting point platinum is the ideal resistor for all temperatures up to 1500°C. If certain simple precautions are observed a platinum furnace may be operated for years without renewal of the heating element. Thus, while the first cost is high, such a furnace may be cheaper in the end. The satisfaction of having a furnace which is in no danger of breaking down at a critical point is often worth the cost. Platinum either in wire or ribbon form may be wound on unglazed Marquardt porcelain or alundum but should not be wound on quartz. In the latter case there is an injurious reaction between the silica and the platinum. This does not occur where the silica is associated with alumina as is the case with the porcelains. Platinum should never be heated in a reducing atmosphere in the presence of metallic vapors. Therefore a reducing atmosphere should be avoided, as metallic vapors are almost sure to be present either from the refractory or the insulation.

Temperatures as high as 1800°C may be reached and maintained with tungsten or molybdenum wire or ribbon, wound on alundum, and protected from oxidation by a hydrogen atmosphere. Molybdenum is to be preferred to tungsten since it can be wound cold whereas tungsten wire must be heated to a dull red before it can be safely bent. Tungsten might be carried to a somewhat higher temperature than molybdenum if a core could be found upon which to wind it. If the resistor is to be used in a vacuum chamber and is not to be wound on a core but can be

supported at points by graphite rods or blocks tungsten may be used for temperatures possibly as high as 2800°C and molybdenum probably to 2300°C. For such a furnace a one-quarter inch tungsten or molybdenum spiral may be stretched vertically between graphite supports arranged in the form of rings at top and bottom of furnace chamber. The spiral is carried from top to bottom and back to top and so on around the ring forming thus a cylindrical heater wall.

Furnace Core. The choice of material upon which the resistor is to be wound depends somewhat upon the temperature range desired. The material should have as high thermal conductivity as possible and the walls should be thin so that cracking will not be caused by rapid, unequal heating. Marquardt porcelain, quartz, alundum, and various other refractory materials are suitable. The porcelains are alumina-silica compounds (kaolin) with feldspar or ball clay binder. Quartz is pure silica. Alundum is fused aluminum oxide, crushed to powder and mixed with a bond of ball clay. It is prepared from bauxite by fusion in the electric furnace. Alundum cores with grooves for spiral resistors are prepared by The Norton Company, of Worcester, Massachusetts. Unless the core is grooved the use of the lathe in winding is quite essential as unequal winding results in unequal heating and local hot spots which, besides making impossible temperature uniformity within the enclosure, shortens the life of the furnace. Thin alundum tubes are very nearly ideal for all ranges to 1800°C. The resistor wire or ribbon of whatever material is wound directly upon the alundum. Marquardt porcelain is considerably more expensive and may be heated only to about 1550°C safely. It has about half the thermal conductivity of alundum but is much less porous which for some purposes may be an advantage. Furnace core tubes should not be glazed. The glaze lowers the softening point of the tube, contaminates the resistor material and usually causes it to adhere to the tube. Renewals are thus difficult and often impossible on the same core. Quartz is satisfactory as a furnace core only for temperatures below 1200°C. In the neighborhood of 1300°C it slowly goes over to an opaque,crumbly form. At 1500°C it begins to soften. If the temperature of the interior is not to exceed 1200°C quartz will make a very satisfactory furnace core. Its low coefficient of expansion makes very rapid heating possible even with thick walled tubes while the transparent tubes offer the possibility of direct visual observation through the furnace walls. For temperatures below 900°C an iron pipe upon which is wound a layer of asbestos paper makes a very good furnace core. The asbestos should be

tied on with thread, the tube dipped in water and the resistor wire or ribbon lathe wound. If wound wet the asbestos will ridge up between the windings and prevent them from touching. Above 1000°C asbestos melts and destroys the resistor. It is advisable to keep asbestos always below 900°C. For temperatures below 500°C windings may be placed on "pyrex" glass. A layer of asbestos is useful here also.

Thermal Insulation. The insulation material is intended to retard the escape of heat and therefore should have the lowest possible thermal conductivity and at the same time be chemically inert and infusible at the highest temperatures to be encountered. The material nearest the furnace core requires different properties than the outer packing for it has to meet different conditions. Chemical inertness and fusing point above the highest core temperature are absolutely essential and must be met, the thermal insulation being merely the best possible consistent with these requirements. Farther from the core better thermal insulation may be obtained often by using materials which would not stand the core temperatures. One inch or more of granular alundum or of granular magnesia next to the core surrounded by an outer supporting tube of alundum or other refractory material makes the best possible packing for extreme temperatures. If the outer tube is surrounded by two inches of magnesia pipe-lagging (such as the 85 per cent magnesia of the Johns-Manville Company) a very efficient arrangement for heat conservation is secured and one suitable for the highest temperature that an alundum core will stand. For temperatures below 900°C the magnesia lagging may be placed directly on the core. Two inches of this will form a very efficient insulation. About one-half inch of asbestos paper on the outside of the pipe-lagging will increase the efficiency of any furnace.

Furnace Construction. A furnace constructed with a core tube 18 inches long and of $1\frac{1}{4}$ inch bore upon which the resistor wire or ribbon is wound with about 1/16 inch clearance between windings will give a 6 inch uniform temperature chamber, if the ends are plugged tightly with granular alundum for about 2 inches. By uniform temperature region is meant a region in which the variation is less than five degrees at 1000°C. The insertion into this chamber of any object which may afford a path for heat outflow will disturb the temperature distribution. If the furnace is used in a horizontal position open at both ends or even at one end, air convection currents through the furnace preclude the possibility of a uniform temperature region. A uniform temperature region may be secured in a horizontal furnace by proper diaphragming.

A diaphragm is placed across the center of the tube and another about an inch and one-half away, the latter with a central opening about one-quarter the area of the tube. This gives a central chamber from which convection currents may be quite completely eliminated by spacing additional annular diaphragms along the tube. The inner of these latter should be of large aperture, nearly that of the tube and the apertures should decrease in size as the outer end of the furnace is approached. The opening in the diaphragm across the end should be about the size of the opening into the inner chamber. This gives approximately the Reichsanstalt black-body furnace and is suitable for optical pyrometry calibration work. If the furnace can be used vertically, open at the bottom but closed at the top with refractory packing for about six inches, a fairly extensive uniform temperature region may be secured. Specimens may be suspended from the top plug or may be elevated from the bottom. It is always better to support the specimen or crucible, containing material under treatment, from the top or sides in order to eliminate heat flow down the support. With a horizontal furnace closed at both ends the uniform temperature region may be improved or extended by spacing the windings more closely toward the ends, or by placing an auxiliary winding for about one-third the way along from each end. This winding may be placed on a tube which slips over the core or upon cement, if cement is used to imbed and insulate the main resistor coil. The spacing arrangement must be effected largely by trial. If the desired result is not secured a different spacing must be resorted to. The windings must be by hand and satisfactory results are difficult to get. With the auxiliary winding plan it is possible to vary the energy input in these windings independently of that in the main resistor coil and gain considerable control of temperature distribution.

An auxiliary winding the whole length of the furnace may be advantageously placed on the alundum tube which supports the inner packing. In this way the temperature gradient across the alumina and core wall may be made very small. This is the "cascade" arrangement. There is a loss of efficiency, since the exterior temperature is raised, but a gain in uniformity of temperature distribution. With this arrangement, although the energy input is greater, smaller current is required in the resistors, which therefore, when the furnace is heating, will not be apt to run so far above core temperature as otherwise is likely to be the case.

If the resistor winding is placed on the *inside* of the furnace core instead of the outside there is a gain in efficiency and in time required to

heat objects in the interior. The furnace core becomes a part of the thermal insulation and the interior walls and objects receive heat by direct radiation from the resistor. The inside winding is accomplished by winding the resistor on a smaller cylinder upon which layers of paper have been wound to a thickness of about 1/16 inch or sufficient to allow the cylinder when wound with the resistor to slip snugly into the core tube. The resistor should then be heated to 400°C or 500°C by passage of current whereupon the inner tube may be withdrawn without disturbing the windings. Upon higher heating the paper will char and burn off leaving the windings against the inner wall of the furnace core. A very thin paste of alundum cement and water may be poured through the tube which upon baking will tightly cement the coil to the furnace core and protect it from disturbance or injury such as may occur on inserting or removing specimens or measuring instruments.

Molybdenum Furnaces. It is well to use fairly heavy wire as with long continued use at extreme temperatures the material becomes brittle. Wire of about .050 inches diameter is a good size. The resistor is usually wound on alundum and packed with finely precipitated aluminum oxide for about four or five inches radially from the furnace core, the whole being contained in an iron cylinder of about 12 inches diameter. Hydrogen is led into one end of the core tube and burned at a small outlet tube at the other end. If a four foot core tube is wound for about 18 inches of its length beginning at about six inches from one end and the heated end insulated with alumina for a length of 30 inches, the other 18 inches being allowed to project through the end of the iron cylinder and exposed to the air except for the protection of an iron sheath for 6 or 8 inches, one will have a very useful furnace, a furnace in which a specimen may be slowly heated or cooled in hydrogen merely by advancing it along the tube from the cold end which will be nearly at room temperature. Such a furnace is very useful when annealing is required without exposure to sudden chill. In the construction of such a furnace care must be taken that the ends are tightly sealed between the furnace core and the iron casing. A refractory cement which sets hard with moderate heating is useful for this purpose. Alundum cement and water will not do, but alundum cement and water glass, thinned with water is satisfactory or such a cement as "Hytemptite" manufactured by The Quigley Furnace Specialties Company, New York, will be even better. These cements should be used as a wash on fire brick or alundum especially cut to fit the ends since a thick layer of such cement will harden on the surface first and then develop cracks

A solid end may be built up by thin layers washed on, with a day between applications. The hydrogen should enter the furnace chamber by a tube through the sealing plug at the hot end and burned as it emerges through a tube or opening near the cold end. The cold end may be fitted with a quartz or mica window. If not sealed tightly the escaping hydrogen should be lighted. A movable alundum plug may be used as a diaphragm between the hot and cold regions of the tube. The hydrogen pressure may be regulated until only a very small flame remains. To avoid explosion the hydrogen should be lighted at the entrance end of the inlet tube as soon as turned on. the flame will then travel along the furnace burning the air quietly until it finally appears at the outlet tube. A light should be held at the outlet tube until the pressure is adjusted and the hydrogen burning quietly. Molybdenum furnaces of the type here described are in general use at the laboratory of the General Electric Company at Schenectady.

Current and Voltage Requirements and Regulation. A furnace of normal size, i.e., one with core winding of 12 to 24 inches length may be connected with a series resistance directly to 110 volt, A. C. or D. C. supply. The current need not exceed 15 amperes for the highest temperatures. If the windings are closely spaced as they should be for best results 10 amperes will be sufficient for the maximum temperatures. The insulation described will permit a temperature of 1500°C for less than one K.W. energy input. Lower temperatures are obtained by inserting series resistance. The small slide rheostats sold by Beck Bros., Philadelphia, James G. Biddle, Philadelphia, or the Central Scientific Company, Chicago, are very convenient for this purpose. With high resistance furnaces such as those of the spiral resistor type a higher voltage such as 165 or even 220 volts may be needed. If such voltages are not available the winding should be in two sections with the leads from the center connected outside and the two halves placed in parallel. Four times the energy input can thus be obtained for the same voltage. It is poor practice to make a central connection on the heated portion of a continuous winding. Any contact made by twisting wires together at such a place will be locally heated and will be certain to burn out. A pressure contact which depends upon elasticity cannot be trusted since elasticity is not retained at high temperatures. The plan of leading the heater wires outside for all connections is the only satisfactory arrangement where the resistance is too high for the available voltage.

Where low-voltage transformers are available windings of very heavy wire (1/8 inch or more in diameter) are sometimes used. The Hoskins Mfg. Company manufactures a furnace in which the resistor is built up of heavy rods bent into hair-pin form and connected in series around the furnace chamber. There is a gain in efficiency with this type since the current may be controlled by means of inductance rather than series resistance. A longer life at maximum temperatures is claimed for such furnaces.

CORNELL UNIVERSITY,
ITHACA, NEW YORK.

The Chemical Action of Ultraviolet Rays. By Carleton Ellis and Alfred A. Wells, 362 pp. The Chemical Catalog Company. Price $5.00.

This book covers both the experimental data of photochemistry and the application of the results to industrial, biological and therapeutic problems. To one who is not in touch with this field of research the range of subjects involved will be a revelation. Sources of ultraviolet rays and the various devices used in technical as well as experimental processes and in therapeutic practice are described fully with the aid of numerous illustrations. Other phases of experimental technique are only casually mentioned in connection with the discussion of results. Five chapters cover the theories and experiments bearing on the chemical action of ultraviolet light. This part of the book will be useful to the specialist as it includes some reference, necessarily brief, to practically all the experimental research in this field. To others it will prove unsatisfactory. The results are frequently conflicting and inconclusive and the authors have made little attempt to systematize or correlate the mass of data. Chapters on the problem of photosynthesis of food from atmospheric gases, and on the biological and therapeutic effects of ultraviolet rays are of much more general interest. A large number of miscellaneous industrial uses of ultraviolet radiation are also described.

One is impressed with the need of more research on the simplest reactions. There is scarcely an instance of a photochemical effect where the physical process is understood. A noteworthy exception is the Cario-Franck experiment on the dissociation of hydrogen by excited mercury. After reading this book one is convinced that the possibilities of photosynthesis will be almost unlimited after a sound theoretical basis is established for the choice of catalysts. The authors deserve credit for accomplishing the difficult task of presenting a large subject in all its aspects and their efforts will do much to stimulate a wider interest in this field.

F. L. MOHLER

THE CARBON TUBE FURNACE*

By Arthur S. King

The purpose of the following is to discuss briefly the features which experience has shown to be most essential in the design and operation of the carbon tube furnace. The literature concerned with electric furnaces is very extensive, but even in the more comprehensive treatments of the subject, little space is devoted to this form of furnace, which has a relatively restricted use in laboratory investigations. However, the following books contain much material which will be found useful in connection with the tube furnace work:

Moissan. "The Electric Furnace," trans. by Mouilpied (Edward Arnold) 1904.
Pring. The Electric Furnace (Longmans, Green and Co.) 1921 (Extensive Bibliography)
Stansfield. The Electric Furnace, its Construction, Operation and Uses (McGraw-Hill Book Company) 1914.
Wright. Electric Furnaces and their Industrial Application. (Constable)1910.

The essential parts of the carbon tube furnace, with the accessories usually required, are as follows: 1. A tube, usually of graphite, heated by the passage of an electric current through its material. 2. Electrode clamps at the ends of the tube, with provision against excessive heating of the clamps. 3. An enclosing screen or jacket of refractory material, to protect the tube against oxidation and to reduce the loss of heat. 4. In the case of a vacuum or pressure furnace, an enclosing chamber, air-tight, through which conductors pass, carrying electric current and cooling water. 5. A source of alternating or direct current of large output, permitting close regulation of the low voltage usually employed.

The Resistor Tube. The tube used as resistor may be either vertical or horizontal. The vertical arrangement is often preferable in melting operations, since a crucible may be supported within the furnace tube, and the melting of the contents observed from above. The best known furnace with vertical tube is that of Arsem,[1] now made and sold by the

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[1] Journal Am. Chem. Soc. *28*, p. 921; 1906.
Trans. Am. Electrochem. Soc. *9*, p. 153; 1906.

General Electric Company. In this furnace, high temperature is obtained with moderate amperage by the use of a tubular spiral of graphite, with connections for current at the ends. A radiation shield surrounds the spiral, and the whole is enclosed in a water-cooled vacuum chamber through a window of which the contents of a crucible within the spiral may be observed.

The horizontal tube is used chiefly for the observation of vaporization phenomena, especially in spectroscopic studies. Methods of electrical heating other than use of the tube as resistor may be mentioned. The tube may be imbedded in granular material such as kryptol, through which the current passes, or wound with a coil of resistance wire insulated from the carbon. As the temperatures thus obtainable are not very high, tubes of the more refractory porcelains, fused quartz, or alundum are generally used in preference to carbon. High local temperatures may be obtained in a carbon tube heated by an external arc, of which the tube is one electrode, or a high-current arc may be formed between terminals supported above the tube, which then acts as a crucible as in the Moissan furnace.

Graphite is generally to be preferred to amorphous carbon as a material of the tube. While the electrical resistance of graphite, when hot, is about one-fifth that of carbon, its thermal conductivity is about double that of carbon, giving more uniform heating of the tube.

The high purity of graphite is very advantageous, as with carbon tubes the constituents of the binding material are vaporized at the higher temperatures. The formation of graphite from amorphous carbon, by the Acheson process, takes place at a temperature so high that most of the impurities in the carbon are vaporized, the regular product being rated as 99.5 per cent pure carbon. If still greater purity is desired, as for spectroscopic work, the Acheson Graphite Company, of Niagara Falls, will supply "regraphitized" material, which the spectroscopic test shows to be almost free from foreign matter, titanium and vanadium being the most persistant impurities.

The ease and accuracy with which graphite may be machined is another decided advantage. Tubes of any desired size may be ordered from the factory or prepared from rods by a laboratory machinist. The boring and cutting tools should be used without oil, and lateral pressure on the rod should be as light as possible.

The bore of the tube and thickness of the wall should, as a rule, be as large as can be heated to the desired temperature by the electrical supply available. In optical experiments, diffuse light from the white-

hot wall becomes disturbing with tubes of small diameter, and the greater mechanical strength of large tubes simplifies the operations. A tube of purified Acheson graphite of 1/2 inch bore, 3/4 inch outside diameter, with 8 inches heated, will give a temperature range from 1200° to nearly 3000° C with a voltage range from 10 to 40 volts, if low-resistance connections are used throughout. The maximum steady current is then about 1600 amperes.

Various devices may be used to render the temperature of the tube more nearly constant throughout its length. The outside may be turned to a slightly smaller diameter near the ends. Wright[2] describes several forms of grooved and subdivided tubes designed by H. N. Potter. If carbon tubes are used, the resistance of the material decreases with increase of temperature. This supplies an equalizing influence which for general work is probably sufficient, as any portion of the tube tending to become cool receives automatically a larger proportion of electrical energy. This is true also for graphite tubes up to about 600°C, but from this point to 1800°C, B. Noyes, Jr.,[3] finds a slow, linear increase of resistance with temperature in the case of Acheson graphite which was not highly purified. Pyrometer tests by the writer have shown that with a graphite tube of uniform cross-section, the temperature variation is small to within about an inch of the electrode clamps, if these are designed to minimize the cooling of the tube.

The fact that many substances combine with carbon, usually resulting in a lowering of their melting points, is often a disturbing feature, though in spectroscopic work it may be an advantage, since the material under examination vaporizes at a lower temperature and a supply of the compound stays in the highly heated portion. Tungsten, as an example, melts below 2700°C when in contact with carbon. Obviously the standard melting points of metals cannot be used to measure furnace temperatures if such a combination with carbon takes place.

Measurements of Temperature. Many forms of pyrometers may be used for the measurement of tube temperatures below 1700°C, and those with a graphite-carbon element even higher. However, the difficulty of inserting pyrometers of the resistance or thermoelectric type if the furnace is in a closed chamber, and the obstruction of the tube and possible disturbance of conditions in any case, make the optical pyrometer usually preferable, even for the lower range of temperature.

[2] J. Wright, Electric Furnaces and their Industrial Applications, p. 236.
[3] Physical Review, *24*, p. 190; 1924.

If an optical pyrometer is to be used without correction, the cavity examined must approximate closely to black body conditions. This is true of a carbon tube closed by a diaphragm, which may conveniently be a small section cut from a graphite rod; and the temperature of any portion of the tube may be measured by sighting the pyrometer on this diaphragm when located at the desired point. If the tube is of fair length and the bore not too large, the diaphragm is not necessary, as the same temperature reading is obtained by sighting on the wall of the interior. Observations by the writer of sensitive spectrum lines showed these to be emitted with the same intensity in different parts of the cross-section from the wall to the center, indicating the equality of temperature to be expected of a black body.

Temperatures Attainable. Up to a temperature of about 2400°C, the constancy of operation of a graphite tube is governed largely by the completeness with which oxygen is excluded. At about 2000°C, especially in the case of a vacuum furnace, the vaporization of carbon becomes perceptible, and above 2400° progresses vigorously. Increased electrical energy then superheats the carbon, and probably a temperature of at least 3500° can be reached. The writer has forced tubes in this way to temperatures much beyond the limit of a Morse pyrometer at 3200°C.

If the conditions of the experiment will allow the use of high gaseous pressure about the furnace tube, the vaporization of carbon may be retarded. The carbon spectrum is very strong at high temperature in a partial vacuum, while at high pressure it is suppressed relatively to the spectra of metals contained in the tube. The effect offers a possibility, by the use of an inert gas at high pressure, of obtaining very high furnace temperatures.

Effect of Contact with Oxygen. In work with the tube furnace, circulation of air about the tube should be prevented by one of the protecting methods to be discussed later, and the complete exclusion of oxygen is of course desirable. If the experiment does not permit of this, the oxidation of the tube, even at temperatures above 2000°, does not proceed so rapidly as to rule out all work under these conditions. The formation of oxides and their spectra may be studied in this way. With tubes of 1/8 inch wall, the writer has used compressed air up to 24 atmospheres and at atmospheric pressure has passed through the tube a stream of pure oxygen so strong as to give a flame several inches long at the farther end. While the life of the tube under such conditions is short, observations such as spectrum exposures lasting some minutes may be carried out.

Use of Lining Tubes. While a vertical tube is usually preferable if a crucible is to be heated, a corresponding use of the horizontal tube with its long column of uniformly heated vapor may be made by inserting an inner tube, insulated by short sections of quartz tubing at the ends, which are cooled by the electrode clamps. A graphite liner will permit the use of high temperatures, and may be charged with substances whose fusion in the current-carrying tube would affect the constancy of its action. Tubes of non-conducting material, such as fuzed quartz or alundum, may be used as liners at temperatures below their melting points, retaining the good heating qualities of the graphite tube furnace.

Electrode Clamps. A low-resistance contact between the end of the furnace tube and the clamp which leads in the current is very essential. This contact receives much heat from the tube, and provision must be made for taking this heat away without unnecessary chilling of the end of the tube, with consequent shortening of the highly heated section. Direct contact of a metal clamp with a carbon tube of small periphery usually results in arcing. Hutton and Patterson[4] coated the end of the tube with copper and soldered this within a copper tube which was surrounded by a water jacket and connected to the current leads. This, however, gives a strong cooling of the furnace tube. The writer has avoided this by fitting around the end of the tube the halves of a graphite cylinder about 4 inches in diameter. These make close contact on two inches at the end of the tube, and can be heated without injury. Clamped around the graphite cylinder, with a large area of contact, is a water-cooled bronze casting, also in two parts, which receives the electric current and also cooling water through flexible copper tubes.

Expansion of the Tube. Little attention has been paid by designers of tube furnaces to lengthening of the tube when heated. The writer's experience has been that little trouble arises from this cause if the end connections for the tube are accurately in line, not rigidly connected with the supporting frame, and if the upper and lower halves of the clamps, which are massive and have large contact surfaces, are not bolted tightly together. The unctuous surface of the graphite allows some slipping within the metal clamp, and the flexible copper tubing for current and water permits a slight movement of the whole terminal connection. A useful device by Potter is illustrated in Wright's

[4] Trans. Faraday Soc. *1*, p. 187; 1905.

"Electric Furnaces," p. 237. The graphite bushing holding the end of the tube is joined to a flexible metal disk (which might be improved by an attached water jacket), and this is bolted along its periphery to a more massive plate to which the current leads are attached. At very high temperatures, carbon becomes slightly plastic. When a tube burns in two, the sections are found to have bent under their weight. This property doubtless lessens the liability to fracture.

Protection against Oxidation and Heat Loss. Unless the furnace is enclosed in a vacuum chamber, a jacket about the tube must be provided to prevent circulation of air and to retard the loss of heat. This may be a refractory material, usually in course powder form, piled around the tube, provided the temperature of the latter is kept below the melting point of the material, which for carborundum, one of the most refractory, is about 2200°C. A more convenient protector is a tubular shield, the inside of which is a graphite tube enclosing the furnace tube with a small clearance, at its ends graphite disks, and around these a covering of asbestos or sheet metal. The space within may be filled with a refractory powder such as lime, alumina, chromite, zirconia, magnesia, carborundum, or powdered carbon. The filling may be stratified, with a very refractory substance such as carborundum around the core and materials of lower melting point but better heat insulation outside. The subject of heat insulation is a large one and is treated in detail in the chapters on "Refractories" in the books of Stansfeld and Pring.

If the furnace is in a vacuum chamber, both oxidation and convection are minimized, and the furnace tube may be allowed to radiate directly to the water-cooled enclosure, in which case the working temperature is reached in a few seconds after turning on the current. Electrical energy is conserved, however, if a jacket is placed around the tube to retard radiation, but this should be of material which will not contaminate the enclosure when heated. Solid graphite may be used, or a graphite shell filled with carborundum, or a number of carborundum plates (sharpening stones) may be built up around the tube and give satisfactory service after the vapor from the binding material has been driven off.

Electrical Supply. Unless thin-walled and correspondingly fragile tubes are to be used, a transformer or direct-current generator of at least 40 kilowatts output is desirable, although a small furnace may be used very effectively with much less power. A low potential range, say from 10 to 40 volts, with a close regulation of the voltage at the supply

terminals, is naturally to be preferred to the use of a series rheostat. If the latter is unavoidable, one of the forms of liquid resistances used in technical operations may be constructed so as to give the voltage control required for the maintenance of constant temperature of the furnace.

Vacuum and Pressure Furnaces. Aside from the Arsem vacuum furnace, the use of a gas-tight chamber has thus far been mainly for spectroscopic investigations. A tube furnace in a vacuum chamber is

FIG. 1. *Electric Vacuum Furnace, Laboratory of Mt. Wilson Observatory.*

not only free from oxidation effects, but the spectrum lines from substances thus vaporized are very sharp. In the pressure furnace, the shift of spectrum lines at high pressures may be studied. In both cases, since the furnace will emit most of the lines present in the arc spectrum, the work can be carried on without the difficulties which result from using an arc at either low or high pressure.

In conclusion, mention may be made of three furnaces designed by the writer. One of these[5] is enclosed in a pressure chamber made to

[5] Mt. Wilson Contr. No. 28; Astrophysical Journal, *28*, p. 300; 1908.

stand 200 atmospheres, several of the features being taken from the design of a pressure arc chamber by Hutton and Petavel.[6] The furnace chamber is a water-cooled steel cylinder, having the furnace parts attached to one of the removable heads. Investigations in which this furnace was used in a variety of ways are described in the Astrophysical Journal beginning 1908. Recently a vacuum furnace[7] has been constructed, embodying many of the features discussed above. This furnace is illustrated in Fig. 1. The ends of the 12 inch tube are held in graphite bushings, and outside of these are water-cooled clamps. A cylindrical iron water-jacket, which may be lined with refractory material, receives the heat radiated by the tube. The furnace supports rest on a base plate containing insulated plugs through which pass copper tubes carrying electric current and cooling water. An iron hood, containing windows and gas connections, may be lowered on the sheet-copper covering of the base-plate. Gas-tight connections throughout are made by the fitting in question having a sharp edge, or in the case of the plugs, a raised ring of metal, which fits against a smooth surface, this surface, where insulation is required, being a fiber washer. Electric current from either a low-tension transformer or a direct-current generator is led into the furnace through 3/8 inch copper tubing, attached to copper bus-bars at the pier. Short lengths of this tubing, water-cooled, will carry up to 2000 amperes and form a conveniently flexible connection. Recently a replica of this furnace was constructed, with all dimensions about one-half those of the larger apparatus. With graphite tubes, having a length of 4 inches heated between the contact clamps, temperatures up to 2300°C were obtained with a power expenditure of about 10 kilowatts.

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PASADENA, CALIFORNIA.

[6] Phil. Trans. Roy. Soc., A*207*, p. 421; 1908.
Electrochem. and Met. Ind. *6*, p. 97; 1908.
See also Stansfield, p. 153.
[7] Mt. Wilson Contr. No. 247; Astrophysical Journal *56*, p. 318; 1922.

THE APPLICABILITY OF WOLFF'S TEMPERATURE FORMULA FOR THE WESTON STANDARD CELL

By Warren C. Vosburgh

It has been found[1] that Weston Standard cells with electrolytes containing small concentrations of sulfuric acid differed only slightly in electromotive force from cells with neutral electrolytes. They were, if anything, more nearly constant and more reproducible. It was of interest, therefore, to measure the effect of temperature on the electromotive forces of the cells prepared for the previous work to determine whether or not the presence of the small concentrations of acid in the electrolyte would affect the temperature coefficient. It was also of interest to determine how closely Wolff's formula[2] held for the various groups of cells.

Wolff[2] derived the formula

$$E_t = E_{20} - .00004075\,(t-20) - .000000944\,(t-20)^2 + .0000000098\,(t-20)^3$$

from measurements of a large number of cells with neutral electrolytes. This formula differed appreciably from previously proposed formulas. Steinwehr[3] found that the earlier formula of Jaeger and Wachsmuth[4] was in better agreement with some calculations from thermochemical data than Wolff's formula. However, Cohen, Kruisheer and Moesveld[5] redetermined the data on which Steinwehr's calculation was based and made the calculation again with results favoring Wolff's formula. They showed that there was an uncertainty in the calculation which made the results of doubtful value in the selection of the correct temperature formula. Cohen and Wolters[6] and Steinwehr[7] have pointed out that whereas Wolff's formula predicts a solubility minimum for hydrated cadmium sulfate at 3° the most reliable data on the solubility show a minimum in the vicinity of −9°. The formula of Jaeger and Wachsmuth predicts a minimum at this point, although an extrapola-

[1] Vosburgh, J. Am. Chem. Soc., *47*, p. 1255; 1925.

[2] Wolff, Bur. Standards, Bull., *5*, p. 326; 1908.

[3] Steinwehr, Z. physik. Chem., *88*, p. 252; 1914.

[4] Jaeger and Wachsmuth, Ann. Physik, 59, p. 575; 1896.

[5] Cohen, Kruisheer and Moesveld, Z. physik. Chem., *96*, p. 447; 1920.

[6] Cohen and Wolters, Versalg. Akad. Wettenschappen Amsterdam, *26*, p. 795; 1918. Z. physik. Chem., *96*, p. 257; 1920.

[7] Steinwehr, Z. physik. Chem., *94*, p. 14; 1920.

tion is involved. Wolff's formula has been the international standard since 1908.

Little has been published on the temperature coefficient of acid cells. Obata[8] measured 4 cells with electrolytes containing 0.04 to 0.38 moles of sulfuric acid per liter at temperatures between 15° and 30°. He found that they all had temperature coefficients larger than the neutral cell and that the coefficients increased as the acidity increased. Vosburgh and Eppley[9] found that the change in electromotive force between 25° and 35° for some cells with electrolytes containing 0.01 moles of sulfuric acid per liter was slightly less than that calculated by Wolff's formula.

PROCEDURE

Nearly all the cells used in this investigation have been described previously.[1] A few details not given in the previous paper are given in the footnotes to Table 1. The cells were kept in an oil thermostat capable of being regulated to $\pm 0.01°$. After they had been maintained at 25° for some time final measurements were made and the temperature was changed successively to 20°, 15°, 20°, 25°, 30°, 35°, 40°, 35°, 30°, and 25°. The cells were maintained at each temperature for from four days to two weeks. Electromotive force measurements were made occasionally, usually every other day during the latter part of the period. The average of the last two or three results, which agreed in most cases within 2 mmv, was taken as the final value.

After a decrease in temperature most of the cells were more or less slow in coming to equilibrium due to the hysteresis which had been observed previously in many cells.[10] In such cases the temperature was kept constant for two weeks, this being sufficient time for assurance of equilibrium in most of the cells. Equilibrium was assumed when three successive measurements two days apart showed that no appreciable decrease in electromotive force had taken place during the four days in question.

After an increase in temperature, cells which had been at or near equilibrium at the lower temperature became constant at the higher temperature almost immediately. The temperature in such cases was kept constant for at least four days, and at least two, usually three, final measurements were made.

[8] Obata, Proc. Math. Phys. Soc. Japan, *2*, p. 235; 1920.
[9] Vosburgh and Eppley, J. Am. Chem. Soc., *46*, p. 110; 1924.
[10] (a) Ref. 2, p. 329. (b) Ref. 9, p. 109.

Electromotive force measurements were made by means of the standard cell potentiometer described by Eppley and Gray,[11] with the use of the previously described Cells 1-12 as standards.[12] The standards were kept in a separate oil thermostat at 25°, except during the first and final measurements at 25° when they were kept in the bath with the other cells. The values given in Table 1 are based on the assumed value of 1.018049 v. at 25° for the average of the nine reference standards. Cell comparisons were probably accurate to 2 mmv or better. The system was shielded as recommended by White,[13] and was tested for parasitic electromotive forces occasionally, but none were noticed greater than 0.5 mmv. The potentiometer was checked, and the maximum error was found to be about 1 mmv.

Temperature measurements were made by means of two platinum resistance thermometers and a standard mercury thermometer and were probably accurate to $\pm 0.01°$. The temperatures were within 0.01° of the even values given, except in the case of the first measurements at 35°. A correction of 2 mmv was applied to these results, as the temperature was 35.04°. Periodic fluctuations of the thermostat containing the standards amounted to about $\pm 0.02°$. In the thermostat containing the other cells the fluctuations were less than $\pm 0.01°$. The uncertainty in the final average results due to temperature errors was probably not much greater than 1 mmv.

RESULTS

The results are given in Table 1. Average values for the various groups of cells are given, the number of cells in each group being shown in the second column. The fourth column shows the electromotive forces at 25° before the first change in temperature, and the fifth shows the average variation of the individual cells from the value given. The other columns give the differences between the electromotive forces at the respective temperatures and the electromotive forces given in the fourth column. In some cases in which it was obvious that the cells had not reached equilibrium at the time of the final measurements no values were included in the table. In other cases, while changes in electromotive force were slow enough to be overlooked, it was thought probable that the decrease would have gone on appreciably further if time had been allowed. The values obtained in such cases are enclosed in parenthesis.

[11] Eppley and Gray, J.O.S.A., *6*, p. 859; 1922.
[12] See Ref. 1, p. 1256.
[13] White, J. Am. Chem. Soc. *36*, p. 2011; 1914.

It is to be noticed that most of the cells showed a small change in electromotive force during the course of the measurements. Thus most

TABLE 1. *Effect of Temperature on the Electromotive Forces of Weston Standard Cells.*

Cells	No. of Cells	Conc. of acid Moles/liter	Average Emf. 25° *V*	Average Variation Mmv	20° Mmv.	$E_t - E_{25}$	
						15° Mmv	20° Mmv
397-406[a]	10	—	1.018065	2	229	410	228
278-283[b]	5	—	1.018055	4.5	—	—	—
296-297[c]	2	—	1.018087	1	227	408	225
320-321[a]	2	—	1.018055	0.5	226	405	225
324-325[d]	2	—	1.018051	0	—	—	—
301-310	6	0.0025	1.018058	4	(235)	(418)	230
312-319	8	.005	1.018059	3	(234)	(417)	230
328,330	2	.011	1.018045	3	222	399	222
353-356	4	.011	1.018046	3.5	222	397	221
420-421[e]	2	.011	1.018092	2	223	398	222

Cells	$E_t - E_{25}$						
	25° Mmv	30° Mmv	35° Mmv	40° Mmv	35° Mmv	30° Mmv	25° Mmv
397-406	2	−260	−560	−888	−556	−257	6
278-283	−3	−267	−567	−893	—	—	—
296-297	2	−260	−559	−887	−556	−258	2
320-321	2	−260	−559	−887	−559	−265	−3
324-325	2	−258	−557	−883	—	(−251)	—
301-310	2	−260	−560	−889	−556	−255	7
312-319	2	−260	−559	−887	−554	−254	10
328,330	2	−259	−558	−883	−555	−259	3
353-356	0.5	−258	−558	−882	−556	−258	0.5
420-421	2	−260	−559	−887	−560	−264	−3

a. Cells 397-406 and 320-321 were very carefully made and seem to be the best neutral cells which have been made in this laboratory up to this time.

b. Cells 278-281 and 283 were selected as typical of a large group of cells made with neutral electrolytes but without sufficient precautions to entirely avoid the presence of introduced mercuric-ion.

c. Cells 296-297 were made with mercurous sulfate prepared by alternating current electrolysis. (See Ref. 1, p. 1266).

d. Cells 324-325 were made like 320-321 except that the paste contained some basic mercurous sulfate made by washing mercurous sulfate with air-free water.

e. Cells 420-421 were carefully made with fine white mercurous sulfate 4. (See Ref. 9, p. 105.)

of the second values at 25° were 2 mmv higher than the first ones, and the final values were from 5 mmv lower to 8 mmv higher than the

second ones. Corresponding changes are shown by a comparison of the two sets of values at 30° and at 35° respectively. While these changes are small they should be taken into account in calculating the variation of electromotive force with temperature. It seems likely that the changes took place when the temperature was decreased. An increase in temperature seems to disturb the equilibrium little, if any, but a decrease makes a disturbance which manifests itself as hysteresis in many cells. In cells showing only a small amount of hysteresis the adjustment to equilibrium, or to a steady state not far from equilibrium, requires only a few days, but it may require considerable time in cells showing large hysteresis. Measurements over a considerable period after the final 25° measurements showed that the cells which apparently had increased in electromotive force were very slowly approaching their former equilibrium values. As this approach to equilibrium was so slow, and the error involved was small, it was assumed that permanent changes took place during the decrease from 25° to 20° and during the decrease from 40° to 35° but at no other time. The differences between the two sets of values at 35° as well as those between the two sets of values at 30° indicate that this assumption is nearly enough correct for practical purposes. Accordingly it was considered sufficient correction to use the second 25° values as the basis of comparison for all the results up to and including those at 40°, and to use the last 25° value for the second 35° and the second 30° results. The temperature

TABLE 2.

Cells	$E_t - E_{25}$, Corrected							
	20° Mmv	15° Mmv	20° Mmv	30° Mmv	35° Mmv	40° Mmv	35° Mmv	30° Mmv
397-406	227	408	226	−262	−562	−890	−562	−263
278-283	—	—	—	−264	−564	−890	—	—
296-297	225	406	223	−262	−561	−889	−558	−260
320-321	224	403	223	−262	−561	−889	−557	−263
324-325	—	—	—	−260	−559	−885	—	—
301-310	(233)	(420)	228	−262	−562	−891	−563	−262
312-319	(232)	(415)	228	−262	−561	−889	−564	−264
228,330	220	397	220	−261	−560	−885	−558	−262
353-356	222	397	221	−259	−558	−883	−556	−258
420-421	221	396	220	−262	−561	−889	−557	−261
Average	225	403	225	−262	−562	−889	−560	−262
Av. Var.	±3	±6	±3	±1	±2	±2	±3	±2
Max. Var.	±6	+12	±6	+4	−6	±7	+7	−5
Wolff	226	404	226	−266	−565	−888	−565	−266

increments calculated in this way are shown in Table 2. Average values obtained by giving all the individual cells equal weight are given, and also the average and maximum variation of the values of the individual cells from the average. Corresponding increments calculated by means of Wolff's formula are given for comparison.

While no measurements of cells with electrolytes of larger acid concentration were made over the whole range of temperatures the effect of temperature on such cells can be deduced from some earlier measurements at 25° and 35°. Cells 143-156, described in a previous paper,[14] were measured at $25.02° \pm 0.01°$ and again at $34.96° \pm 0.03°$. Subsequent measurements at 25° showed that they did not change appreciably during the temperature changes. The results, together with the

TABLE 3.

Cells	Concn. of acid Moles/liter	Emf. 25° Mmv	$E_{34.96} - E_{25.02}$ Mmv	$E_{35} - E_{25}$ Mmv
143-145	0.021	1.018044	−555	−559
146-148	.035	1.018016	−557	−561
149-151	.048	1.017978	−552	−556
152-154	.064	1.017966	−556	−559
155-156	.078	1.017938	−555	−558

concentrations of acid in the electrolytes, are given in Table 3. In the last column 3.5 mmv are added to the electromotive force increments to correct them to the full ten degree interval for comparison with the results in Table 2.

DISCUSSION

It is shown in Table 2 that the various groups of cells agree closely as to temperature coefficient and that Wolff's formula holds for all. The electromotive force increments calculated by means of Wolff's formula agree with the averages of the observed increments within 1 to 5 mmv. The average variation of the individual cells from the mean values was small, in most cases 2 or 3 mmv, and was as much as 6 mmv only in the 15° values. The maximum variation from the mean values was usually about 6 mmv and was as much as 12 mmv for only one cell at 15°. It is to be concluded therefore that for all properly constructed normal Weston cells with either neutral or slightly acid electrolytes calculation by means of Wolff's formula will give the difference between the electromotive force at any temperature between 15° and

[14] Ref. 1, p. 1263.

40° and that at a standard temperature within about 10 mmv, or 0.001 per cent of the electromotive force of a cell.

Although cells with slightly acid electrolytes have practically the same temperature coefficients as neutral cells there seems to be a very small difference. The electromotive force measurements for the last three groups of cells in Table 2 are nearly all below the average. This may be due to the greater constancy and negligible hysteresis of these cells or it may be a real difference. Table 3 shows that with increasing acidity of the electrolyte there is no change in the electromotive force increment for the temperature interval 25° to 35°. This argues against the assumption of a real difference in the temperature coefficients and makes it seem likely that the small apparent difference is due to experimental errors. The errors in question are probably in the values of the neutral and the first two groups of acid cells, all of which showed some hysteresis, and are probably due to the cells not attaining complete equilibrium at the time they were measured. Wolff's formula, therefore, should hold for all practical purposes for acid cells with concentrations of acid up to 0.08 moles per liter.

This conclusion is not in agreement with the results of Obata.[8] For the electromotive force increment between 20° and 30° of a cell with an acid concentration of 0.04 moles per liter Obata's data gives 655 mmv while Wolff's formula gives 492 mmv.

SUMMARY

The electromotive forces of a number of normal Weston cells, some with neutral and some with slightly acid electrolytes, were measured at 5° intervals over the range 15° to 40°. Some other cells with electrolytes containing 0.02 to 0.08 moles of sulfuric acid per liter were measured at 25° and 35°. Wolff's temperature formula was found to hold for all, the presence of acid being found to have little or no effect on the temperature coefficient.

THE EPPLEY LABORATORY,
NEWPORT, R. I.

A NEW SPIRAL GAS-WASHING BOTTLE

BY LOWELL H. MILLIGAN

A new spiral gas-washing bottle has been designed in order to meet severe requirements. The new bottle gives excellent contact for a long time between the gas and a definite volume of liquid so that there is good opportunity for complete absorption or saturation of the liquid with gas; the liquid is thoroughly circulated so that all of it is brought into contact with the gas; there are no dead spaces to trap any of the gas.

The bottle consists of four parts, which are rugged and can easily be taken apart for cleaning: an outer cylinder (1), a cylindrical shield (2) fitting loosely into the outer cylinder and serving to support and fit closely to a heavy inner cylinder (3) the walls of which are pressed in the form of a spiral, and a gas inlet tube (4) integral with a groundglass stopper and outlet tube. The bottle is filled with liquid up to just above the top of the spiral. The inlet tube serves to introduce the gas at the base of the spiral, and the gas bubbles travel slowly upward circling around the spiral in contact with the liquid until they escape at the surface. The liquid circulates upward with the bubbles and then downward both through the center of the spiral and around the outside of the shield.

The important features of this bottle have been patented, and it is now available, of American manufacture, fitted with either a groundglass stopper or a rubber stopper, under the name "Milligan gas-washing bottle."

NORTON COMPANY RESEARCH LABORATORIES,
WORCESTER, MASS.

A LABORATORY MERCURY LAMP

By E. O. Hulburt

A brilliant mercury lamp of pyrex or quartz simple to construct in that all the seals are of wax is shown in Fig. 1. The lamp is blown from pyrex or quartz tubing of about 6 to 7 mm internal diameter and of wall thickness about 1.4 mm. Iron electrodes for connection to the mercury are sealed in at *b* and *c* and a glass stopcock *s* is put on at *a* using dekotinski cement or red sealing wax for the seals; if the cock and tube are of pyrex the wax seal at *a* may of course be dispensed with. The lamp is filled with clean mercury, pumped out and is sealed off from the pumps by means of the stopcock; it is burned in an upright position. On account of the shape of the lamp and the linear dimensions indicated in the figure, the wax seals are sufficiently cooled by the natural air convection about the lamp. Moderate constrictions of inside diameter about 2 or 3 mm at *m* aid in preventing the distilling mercury from reaching the seal *a*. It is important to introduce just about the correct amount of mercury, such that the distance between the surfaces *d* and *e* of the two mercury columns when cold is about 3 cms.

In order to exhaust the lamp as thoroughly as possible, since baking out is precluded, the lamp is connected to the pumps by flexible rubber tubing and is tilted at various angles during the pumping so that the mercury flows about allowing as much gas as possible to be drawn off. With the pumps running continuously the lamp is then lighted for some minutes, and after being put out and allowed to cool is put through tilting process again, finally being sealed off with the stopcock. It is lighted by merely tilting back and forth a number of times until warm enough to burn steadily. A lamp made in this way has a life of perhaps twenty hours or more, after which time gases appear in sufficient pressure to make starting difficult. It may then be put back on the pumps and in a few minutes is ready for use again. Various modifications in the shape of the lamp were tried, such as placing bulbs and bends at numerous places, but these appeared to offer no particular advantages over the more simple form of Fig. 1. Although this type of lamp is of course inferior in dependability to one more carefully constructed with high temperature seals[1] and more highly evacuated, yet it has been found to

[1] J.O.S.A. & R.S.I., *11*, p. 549; 1925.

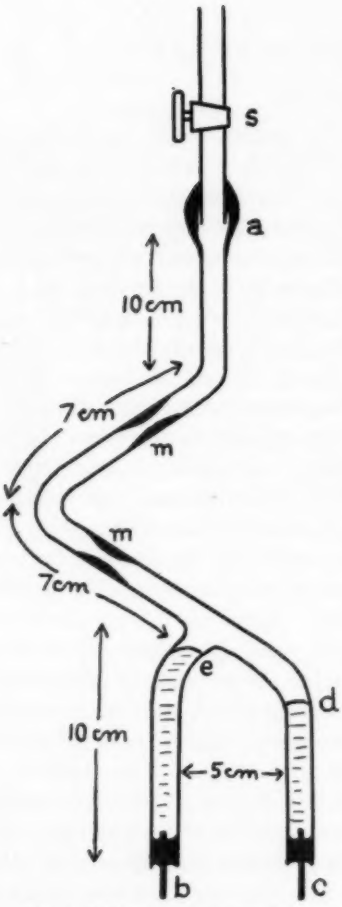

Fig. 1. Laboratory mercury lamp.

stand up well under surprisingly rough treatment, and its short life is partially offset by the ease of construction and renewal.

Since the internal diameter of the lamp is rather small the light is relatively intense. With a current of two amperes, which may be considered a normal current consumption, the lamp was about as bright as the "Lab Arc," or the small Cooper Hewitt quartz lamp, as indicated by a spectraphotometric comparison of the mercury lines of the visible spectrum, and with about five amperes was 10 to 20 times more brilliant. Currents of as much as eight amperes could be used without immediate harm to the lamp for short periods of time. At the higher current densities the pyrex lamps evidenced a characteristic type of failure. In many cases there appeared suddenly and without warning a minute pin hole in the wall of the tube in the path of the discharge, due, as far as could be seen, to a sudden development of intense local heating sufficient to melt the pyrex glass. The phenomenon may perhaps have resulted from the formation of some impurity on the wall of the tube which caused the unusual heating by catalytic action on the vapors of the discharge, somewhat in the manner of the action of atomic hydrogen in the discharge tubes investigated by Wood.[3]

HEAT AND LIGHT DIVISION,
NAVAL RESEARCH LABORATORY,
WASHINGTON, D. C.,
NOVEMBER 23, 1925.

[2] J.O.S.A. & R.S.I., *6*, p. 1066; 1922.
[3] Phil. Mag., *44*, p. 538; 1922.

LINEAR AMPLIFICATION OF GALVANOMETER DEFLECTION BY THE PHOTOELECTRIC CELL

By F. E. Null

Y. T. Tykociner and Dr. Jacob Kunz have suggested a simple and convenient method for securing linear amplification of the deflection of moving mirror instruments by the use of the photoelectric cell. A beam of light of constant intensity is reflected from the mirror of the moving system to a triangular slit in front of the photoelectric cell. The optical and electrical arrangement is shown in Fig. 1. As the first galvanometer is deflected, the image of the vertical slit moves across the triangular slit, and the intensity of the light entering the photoelectric cell has a linear relation to the galvanometer deflection. And,

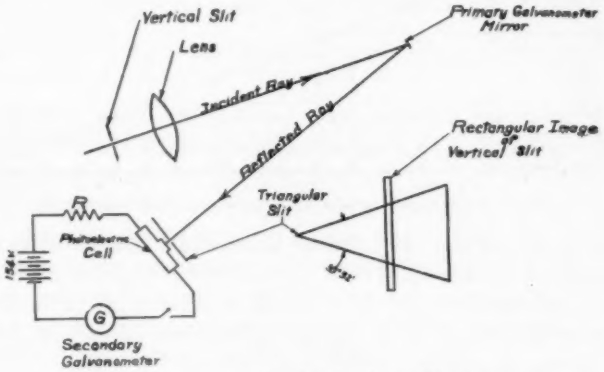

Fig. 1. *Arrangement for photoelectric amplification*

thus, as shown in the graph of Fig. 2 a linear relation is obtained between the secondary galvanometer deflection and that of the primary galvanometer mirror. In these measurements the maximum intensity of light entering the photoelectric cell was equal to 7.04×10^{-3} lumens, or was equivalent to the intensity of light entering the photoelectric cell through an area of 5.3 sq cm from a 3.32 candle power light on the normal to the surface at a distance of 1/2 meter. The figure of merit of the secondary galvanometer was 2.04×10^{-9}.

The amplification graph of Fig. 2 was taken with one of Dr. Kunz's ordinary type of photoelectric cell in which the light enters through a window of the bulb. Due to the curvature of the glass, the amount of light reflected depended upon the position of the entering light beam.

By using a plane glass portion for the incident light on the cell, even this small effect could be overcome, and a very accurate linear relation obtained.

We were interested primarily in securing a linear relation, and used only a weak beam of light (7.04×10^{-3} lumens as noted above). From Fig. 2, it is seen that the amplification secured from this weak source is 71.1/38.5, or equals 1.85 mm deflection of the secondary galvanometer per minute of arc. This figure can be increased very much by increasing the light intensity 10 times, with a corresponding change in the potential difference applied to the photoelectric cell, by increasing the distance between the moving mirror and the photoelectric cell 3 times

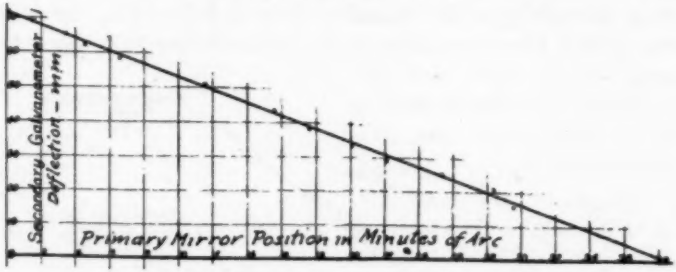

FIG. 2. *Amplification curve of photoelectric cell with triangular slit*

(our distance was 105 cm), and by increasing the angle of the slit at least twice (our angle was 17°15′) so that the sensitivity could readily be increased $10\times3\times2=60$ times, which would thus give a linear amplification of $60\times1.85=107.6$ mm deflection/min. of arc, or, 1.85 mm deflection per sec. of arc.

The photoelectric cell has the very important advantage over the thermocouple that it has no lag, and does not need elaborate protection from temperature fluctuations. Due to its instantaneous action it can be used for the linear amplification of the deflection of very short period instruments. Thus, a minute ballistic throw of the primary galvanometer could be amplified linearly, and read from a secondary galvanometer of the same free period. Or by amplifying the current from the photoelectric cell by one three electrode vacuum tube, the movements of such short period and relatively large current instruments as the syphon recorder (used in ocean cable signal reception) can be amplified.

LABORATORY OF PHYSICS,
UNIVERSITY OF ILLINOIS,
URBANA, ILLINOIS.
OCTOBER 30, 1925.

GREATER DISPERSION IN THE EXTREME ULTRAVIOLET

By R. J. Lang and Stanley Smith

ABSTRACT

A Two-Meter Vacuum Spectrograph.—The construction and operation of an optical vacuum-grating spectrograph capable of accommodating a grating of two meters radius of curvature is described. Means are provided for introducing and removing the photographic plate as well as altering the focus and inclination of the grating while the vacuum is maintained.

Doublet Separations in C II.—The following doublets in Fowler's series have been resolved and the frequency separation measured. $(2\pi_1-3\sigma)(2\pi_2-3\sigma)$ $\Delta\nu=64$ in the second order of the grating and 60 in the third order. $(2\pi_1-3\delta)(2\pi_2-3\delta)$ $\Delta\nu=64.5$ in 2nd order. For lines $\lambda 1335$ $\Delta\nu=65$ and lines $\lambda=1036$ $\Delta\nu=62$ showing that since the 1036 line belongs to C II probably 1335 does also.

Doublet Separation in Si III.—In these series the following doublet is resolved. $(3\sigma_1-4\pi)$ $(3\sigma_2-4\pi)$ $\Delta\nu=153$.

The need for greater dispersion in the Shumann region has become increasingly evident in recent years especially with the discovery of so many ionised atom series. The complexity of the spectra in this region is such that it has become imperative to be able to measure wave lengths with a greater accuracy than has usually been the case before the lines may be definitely assigned to their proper series. In the present paper an account is given of the construction and use of a vacuum-grating spectrograph employing a grating of 192.1 cm radius of curvature, and some preliminary results obtained with it.

In a previous paper by one[1] of us a spectrograph using a grating of 100 cm radius was described and the spectra for some twenty elements recorded. The present spectrograph, while of course longer, has been constructed somewhat along the same lines as the former but includes several novel features which have made its use possible and therefore it seems worth while to publish a short description of the new instrument before proceeding to record the measurements which have already been made by means of it.

A horizontal plan of the instrument is shown in Fig. 1 while Fig. 2 shows a vertical elevation. The main body A consists of a seamless brass tube 20.3 cm in diameter and 225 cm long. The grating mounting G, the plate glass window R, the large opening L for access to the grat-

[1] R. J. Lang, Trans. Roy. Soc., *A*, *224*, pp. 371-419;

ing and the opening K to the rough vacuum pump are all essentially the same as in the previous spectrograph and therefore require no further description.

The end of the tube remote from the grating is enclosed by a special brass casting the form of which is illustrated to the best advantage in Fig. 1. The source may be a high-potential spark or an arc as desired and is formed in a separate chamber consisting of a circular brass tube 12.5 cm in diameter and 20 cm long with its axis set perpendicular to the axis of the main body as shown by the dotted circle with center at O.

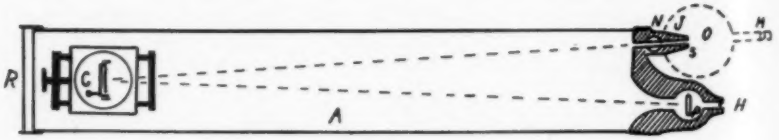

FIG. 1

This chamber has bakelite ends which serve for insulation and is attached to the spectrograph by the conical ground joint J which projects into the source chamber as shown. A large metal tap, formed in the solid brass casting at N, when open allows the radiation to pass freely

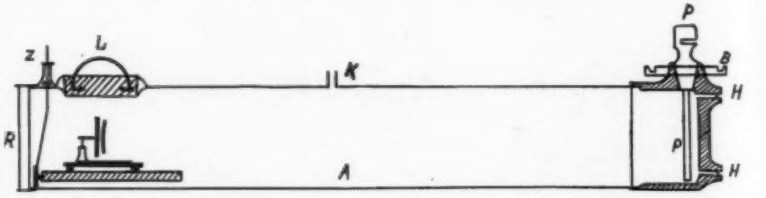

FIG. 2

from the source at O to the grating surface, and when closed effectually separates the source-chamber from the main body of the spectrograph for vacuum purposes. This metal tap is made exactly on the principle of a large glass tap except that the small end (lower end) of the barrel is closed to the atmosphere. The bore of this tap is 1.27 cm.

The plate-holder P holds the plate in a vertical position exactly the same distance from the grating as the slit which is situated in the end of the ground joint J at S. The slit and the lines on the grating are horizontal. This plate-holder is part of a tapered steel plug carefully ground into a tapered opening in the casting so that when the plate-holder is

inserted into the spectrograph the plug makes a perfectly gas-tight stopper for the opening. Two plates are accommodated one on each side of the holder, the interchange being effected while the vacuum is maintained simply by rotating the plug through 180°. The windows *H* coincide with openings in the plate-holder and may be used for roughly focussing the grating.

Hitherto many have thought it next to impossible to evacuate a volume of 70 liters such as this and maintain it at the very low pressure necessary to the production of the high-potential spark. We have found it quite possible, however, by the use of a General Electric two-stage, rotary, oil-sealed pump, as a rough pump attached at *K*, to reduce the pressure in half an hour to such a degree that the Kurth diffusion pump, attached to the source-chamber at *M*, and backed by a Hyvac mechanical pump, would begin to operate. The valve at *K* is then closed and the evacuation continued by the diffusion pump train alone. We have found, of course, that when the instrument is first exhausted it requires some time to reach a stage at which the spark may be used, and that the longer the instrument can be used without admitting air the better the vacuum becomes each time the instrument is operated. On this account it was realized several years ago by the first-mentioned author, who designed and built the present apparatus, that if some method could be devised for introducing and removing the photographic plate from the spectrograph without admitting air there then seemed to be no insurmountable obstacle to the use of a grating of several meters radius thus obtaining as large a dispersion in the extreme ultraviolet as has already been obtained in the visible region. Consequently much thought was given to the design of some mechanism by means of which this might be done and the following is a description of the apparatus which has successfully accomplished this end.

The lower part of Fig. 3 is an end-on view of the spectrograph proper showing the plate-holder end, and the upper part of the figure shows the device for introducing and extracting plates from the spectrograph without admitting air. The latter consists essentially of the buffer-chamber *S* 10.8 cm in diameter, and the use of two exactly similar plate-holders *X* and *Y*. The method of procedure is as follows: At the lower end of the figure the holder *Y* is shown in position in the spectrograph. When the plates on this holder are to be removed the buffer-chamber *S*, already containing the other holder *X* with its two unexposed plates, is placed in a vertical position with its base in the wide groove in the brass collar shown at *B*. The bottom of the groove and

the lower end of S have been carefully machined and ground to fit so that a little vacuum wax on the surfaces is all that is needed to produce a vacuum tight joint, thanks to the large atmospheric pressure forcing these faces together. S is now evacuated by means of the Hyvac pump which is also permanently connected at Q. The volume of S is about six liters and the pressure is sufficiently reduced in about fifteen minutes. The holder Y is now drawn to the top of the chamber S as shown by means of the half-inch steel rod which may be screwed into its upper end. The holder X is now swung into position by the eccentric, attached to the second steel rod, and pushed down into the opening in the spectrograph originally occupied by Y. The air is now admitted to S by the tap t and the chamber removed, whereupon the holder X may be withdrawn and its plates developed. The possibility of leaks at the openings for the sliding rods at the top is taken care of by making ordinary steam stuffing-boxes around each and covering the same with a small vessel full of vacuum oil such as is used in all ordinary vacuum pumps.

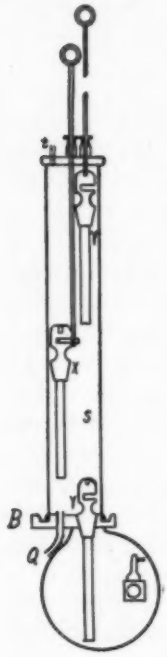

FIG. 3

This arrangement has been found to work perfectly. The usual time required to exchange plates is about half-an-hour. We do not go to the trouble of evacuating S to a very high degree by the use of a diffusion pump as we desire only that, after the operation is completed, the vacuum in the main spectrograph may be still sufficiently good to allow the diffusion pump to commence operations without any preliminary pumping with a rough pump. This is always attained. In fact it is quite possible to preserve a soft x-ray vacuum throughout the operation. This, of course, is because of the fact that, while the vacuum in S is not so high as in the spectrograph chamber when the holder is extracted, the volume of S is so much the smaller that the pressure in the spectrograph chamber is not greatly altered.

The metal tap J makes it possible to change the electrodes by admitting air only to the source-chamber which is quite small and the attachment at Z allows the focus and also the tilt or inclination of the grating to be altered while the high vacuum is maintained.

It must be borne in mind that the chief advantage in the use of this device for extracting plates does not consist primarily in the gain in time by not having to exhaust the spectrograph for each exposure, great as that is, but rather in the fact that the spectrograph may be kept under high vacuum for weeks at a time so that all small gas-pockets or gas-traps which continually seep into such a volume, to the despair of the operator, have long since been exhausted and also the gas given off by the metal surface has been reduced to a minimum.

MEASUREMENTS

In 1924 when Fowler published his series in singly-ionised carbon[2] the dispersion at his disposal did not enable him to resolve the pairs of doublets in the Shumann region. His calculated value for the constant frequency separation of the doublets in the First Sharp and First Diffuse Series was given as $\Delta\nu = 58$.

We have now been able to measure directly this separation for the first pair of each of these series in the second and third order of our grating. For the first pair of the First Sharp Series ($\lambda = 858$) we find that $\Delta\nu = 64$ using the second order and $\Delta\nu = 60$ in the third order. This separation was measured on nine plates in the former case and three in the latter using a comparator reading to 0.001 mm and taking the average of ten settings on each component. The first pair of the First Diffuse Series ($\lambda = 687$) was measured only in the second order and on two plates. We find for this line that $\Delta\nu = 64.5$.

We have also measured the separation of the two components of 1335 and also of those at 1036A. Fowler records the latter as a member of a combination series belonging to C I but has not included 1335 among his C I lines. Millikan[3] has, however, found that the doublet separation of each of these pairs is the same and hence assigns 1335 to C_I. Our measurements would appear to confirm this since we find that for 1335 $\Delta\nu = 65$ and for 1036 $\Delta\nu = 62$. These measurements were made on seven plates using the second order.

We have also made a few measurements on the doublets of Si IV[4]. Quite a number of these doublets have not been resolved and should fall within the possibilities of our instrument but in most of the cases tried these lines are masked by other denser lines on the plates and so far we have not been able to bring them out clearly. We have, however,

[2] Fowler, Proc. Roy. Soc., March, 1924.
[3] Bowen and Millikan, Phys. Rev., September, 1924.
[4] Fowler, Proc. Roy. Soc., June, 1923.

measured the separation of the components of the second member of the First Principal Series ($\lambda = 457$) for which we find $\Delta\nu = 153$.

Since the foregoing was written, we have obtained another grating from Professor Wood of Johns Hopkins ruled with 30,000 lines per inch and having a radius of six feet. The dispersion of this grating is about 4.5 A per mm in the first order which is slightly less than twice that of the former. The shortest wavelength registered by this grating was about 570 A and below 1000 A it was not nearly so effective as the previous ruling. It is, however, an excellent instrument for longer waves and we have succeded in repeating some of our former measurements with it especially on the carbon doublets at $\lambda = 1335$ and $\lambda = 1036$. We find excellent agreement for these with our previous measurement obtaining as an average value for the former pair $\Delta\nu = 65.65$ in the first order and $\Delta\nu = 65.7$ in the second order and for the latter pair $\Delta\nu = 62.6$ in the second order and $\Delta\nu = 62.6$ in the third order which is equivalent to the twelfth order of a one-meter grating with 14,000 lines per inch.

The decision reached above, that these pairs belong to the same ionisation of carbon must therefore be reversed. It appears clear that the difference in $\Delta\nu$, while small is quite real and definite.

It should be noted that our value for the pair at 1036 lies about midway between Simeon's value of 58 and Millikan and Bowen's value of 66.76.

On account of the lack of effectiveness of this grating for short wavelengths we were unable to obtain a measure of the separation of the pairs of carbon doublets at 858 and 687.

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AN OPTICAL SYSTEM FOR READING THE ANGULAR DEFLECTION OF A MIRROR*

By I. C. Gardner

ABSTRACT

With the usual lens, mirror and straight scale method of reading deflections, the indicated value is proportional to the tangent of the angle of deflection. In many instruments, for example in extensometers, in which the motion is communicated to the mirror by the rolling of axis of mirror or by a pinion and geared sector a deflection on a plane surface proportional to the angle of deflection is desirable. This is particularly true if deflection is registered on a moving photographic film as it gives an equicrescent scale in each direction. A simple two lens system which can be satisfactorily made on standard spectacle tools has been designed which introduces distortion sufficient to give desired relation between deflection and indicated value and at the same time gives notable flattening of field, thus permitting the photographic registry of very large deflections. Other simple relations between deflection and indicated value may be secured by redesign of the projecting system.

A rotating mirror and a lens which projects a spot of light reflected from the mirror upon a moving photographic film is a common means for recording transient phenomena. If the film is moved at a uniform rate, the record obtained is a graph in which one has along the one axis an uniform time scale and against which are plotted distances which serve as a measure of the angular displacement of the mirror. The optical system usually employed is either a concave mirror or a plane mirror and a converging lens displaced from the mirror only so much as is necessary to avoid mechanical interference. With either system, the deflection of the spot of light recorded on the film is approximately proportional to the tangent of the angle through which the mirror has rotated.

In a large class of recording instruments it is very desirable to have the deflection of the spot of light proportional to the angular displacement of the mirror rather than to its tangent. This is notably true of many types of extensometers in which a rolling motion is imparted to the mirror through a shaft upon which it is mounted. This proportionality can be secured to any desired degree by decreasing the sensitivity of the recording mechanism in order to reduce the total extent of angular motion of mirror as the departure from exact proportionality between tangent and angle decreases rapidly with the decrease of

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magnitude of the angle. This, however, has the disadvantage that the deflection on the film becomes small and the scale to which the graph is plotted becomes very close unless the distance from mirror to scale is made inconveniently large.

The concrete problem which suggested the optical system described and which illustrates the above was as follows: A recording extensometer is to be built in which it is desired that the total travel of the spot of light on the film be 300 mm and the departure from a linear relationship between the reading indicated by spot of light and angular rotation of mirror must not be greater than .0005 of the deflection at any point within the range utilized.

Reference to a table of natural tangents shows that the tangent and angle are proportional within this limit provided that the maximum deflection does not exceed 2.2°. A deflection of $\pm 2.2°$ will be recorded as a movement of 300mm if the scale distance is 3900 mm. But in the particular instrument to be designed such a scale distance is inconveniently long and the sensitivity of the instrument is such that a much shorter distance may be caused to give a sufficiently large deflection provided that the indication may be held proportional to the angular rotation of the mirror to the required accuracy.

Optically the problem becomes the following: The mirror[1] of the recording system is the component which limits the size of the beam of light transmitted and it is, therefore, replaced by the diaphragm M of the lower part of Fig. 1. The lens is at L and the photographic plate at P. Two beams of parallel light are shown entering the diaphragm and they correspond to the position of the mirror when turned through O and $\alpha/2°$. If one has an optical system which introduces no distortion, the spot of light will be at A' where

$$\overline{OA'} = f \tan \alpha$$

or to a first approximation

$$\overline{OA'} = f\left(\alpha + \frac{\alpha^3}{3}\right)$$

[1] In all cases discussed it is assumed that the mirror is plane and that the bundle of rays entering the optical system after reflection from the mirror is parallel. If the source of light is placed at the same distance from the mirror as the scale, and its light passes through the optical system before incidence upon the mirror, this condition obtains. This is the arrangement of light, lens, plane mirror and scale commonly employed. If it is desired to position the source independently of the position of film, a second collimating system may be employed to render the incident bundle parallel. To avoid mechanical interference between the two optical systems, the reflection from the mirror for the null position may be other than normal.

But it is desired that the spot of light fall at A, where

$$\overline{OA} = f\alpha$$

Therefore, an optical system is desired which will introduce a linear distortion equal to $-f\frac{\alpha^3}{3}$ or an angular distortion (measured at center of lens) equal to $-\frac{\alpha^3}{3}$. The third order distortion introduced when the diaphragm of an optical system is displaced along the axis from the plane of a thin lens is proportional to α^3. By choosing the proper shape

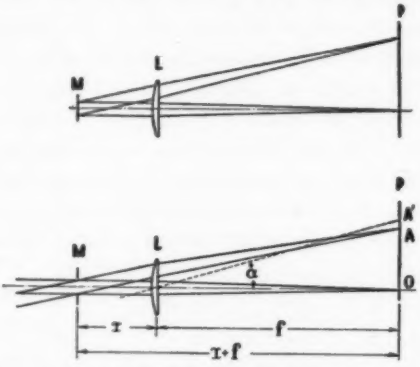

FIG. 1. *Single lens system which gives reading proportional to the angular deflection of mirror.*

for the lens and selecting the proper value of x, the distance from diaphragm to lens, it should be possible to introduce the angular distortion which is required to bring the deflection proportional to the angular rotation of the mirror.

In the first solution obtained, to make the results as simple as possible a single lens is employed. In order to make the results convenient for application, it is assumed that a plano-convex lens made of spectacle crown ($n_D = 1.52$) is to be used. A lens of this character can be readily procured from any optician. By the usual Taylor[2] third order formula, it is found that if the distance from lens to mirror is .17 of focal length of lens and lens is turned with convex side toward mirror, thd required distortion is obtained.

The table below shows the accuracy with which the required relationship is fulfilled. It is assumed that a 1 diopter lens (E.F.L. = 1000 mm)

[2] Taylor, A. System of Applied Optics, Sec. IX, Macmillan & Co., London.

is used in which case the distance from mirror to lens is 170 mm, and from the mirror to photographic film or scale is 1170 mm.

Angular Rotation of Mirror	Computed Deflection	Deflection Proportional to Angle	Deflection Proportional to Tangent
10°	174.50 mm	174.53 mm	176.33 mm
20°	347.30	349.06	363.97
25°	409.38	436.33	466.31

The first column gives the angle through which the beam of light is rotated, (double the angle through which the mirror turns). The second, the deflection as determined by trigonometric ray tracing. The third, the desired deflection based on a strict proportionality between angle and deflection, and the last column gives the deflection when there is no distortion, i.e., when the deflection is proportional to the tangent of the angle. The values corresponding to the larger values of the angles are tabulated in order to show more clearly the manner in which the distortion decreases, the departure from the linear relationship between deflection and angular rotation. It is evident that for an angular rotation somewhat greater than 10° the deflection satisfies the initial requirement, i.e., that departure from proportionality be less than five ten-thousandths of the deflection. But the curvature of field imposes a narrower restriction. For large deflections, the image becomes very poor and $\pm 6°$ is as great a deviation as can be usefully employed. With this deflection, the travel of the spot of light is 300 mm for a scale distance of 1400 mm and this represents a considerable gain over the 3900 mm originally required.

The effectiveness of the above described system is greatly curtailed by the excessive curvature of field which prevents the use of large deflections. To remove this limitation a two lens system has been designed which is illustrated in Fig. 2. The constructional data of the lens system are given below:

	MIRROR	
1		120
1.52	∞	3
1	+ 624	120
1.52	+1302.7	20
	− 410.3	

The first and third columns give the indices of refraction and axial thicknesses of the media in order beginning with the rotating mirror. The air spaces are those for which the index of refraction is 1.

The central column gives the radii of curvature, positive values indicating surfaces convex toward the incident light. This data is as obtained from a solution of Taylor's third order formulas and the focal

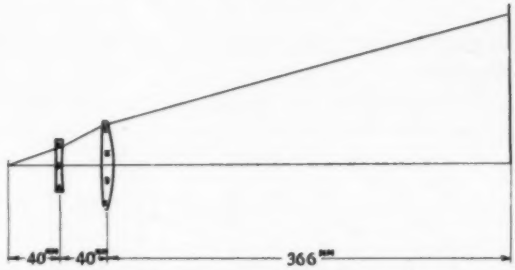

FIG. 2. *A two lens system which gives reading proportional to the angular deflection of mirror and a flat primary image surface.*

length is approximately 1000 mm. The system consists of one plano concave and one double convex lens separated by a space of 120 mm. The thicknesses as given permit the converging lens to be given a diameter capable of transmitting a field with the half angle approximately 20°. Below are given the values of distortion as determined by trigonometric ray tracing.

Angle	Actual Deflection	Proportional Deflection	Difference
10°	173.36 mm	174.31 mm	.95 mm
20°	345.76	348.62	2.86

The third column gives the deflection if strict proportionality were realized. The last column gives the departure of the performance from the ideal desired deflection. This is larger than the tolerance originally set. However, the work at hand was not believed to justify another computation. It was accordingly decided to secure further adjustment by varying the two air spaces in the system at the time of assembly. This procedure was especially to be selected as the lenses are to be ground and polished by standard spectacle lens tools to avoid the expense of special tools and this necessitates a small departure from the curves as designed. Below is given the longitudinal primary curvature,

i.e., displacement of primary image point from plane normal to the axis through the paraxial focus.

Angle	Long. Pri. Curvature
10°	+ .65 mm
20°	+7.48 mm

The positive sign indicates that the image surface is concave toward the on-coming light.

In Fig. 3, for comparison the departures from proportionality between deflections and angular rotation of mirror are plotted. The

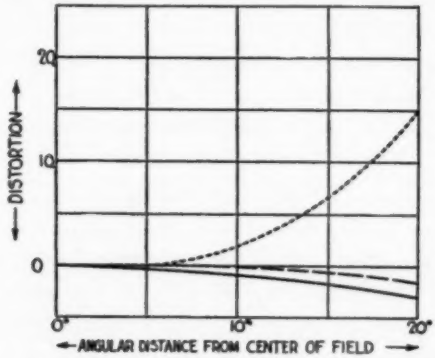

FIG. 3. *Distortion vs. angular distance from center of field.*

The dotted curve applies to single lens in plane of mirror. The dashed curve applies to single lens with mirror .17 f from lens. The full curve applies to the two lens system.

The ordinate is the difference in millimeters between the actual deflection and an assumed deflection proportional to angular displacement of mirror for a lens system of which the focal length is 1 meter. A positive value indicates that the actual deflection is greater than the desired deflection. The abscissa is the angular deflection of the pencil of light, i.e., twice the angle through which the mirror rotates.

dotted curve shows the departures arising when the tangent law is followed, i.e., when the lens is in the plane of the mirror. The dashed curve is for the single lens, distant .17 from the mirror and the full curve is for the two lens system. Similarly the curvature of image for the three systems is indicated in Fig. 4. The very flat field yielded by the two lens system permits a very large deflection to be utilized and thus shortens the scale distance greatly.

The lens system as actually constructed was made according to the following specifications:

	MIRROR	
1		40
	0	
1.52		1
	−2.50	
1		40
	+1.25	
1.52		7
	+3.75	

The significance of the three columns is as before except that the curvatures in the middle column are indicated by the refracting power, in diopters, of the surface. A positive value indicates a convex surface.

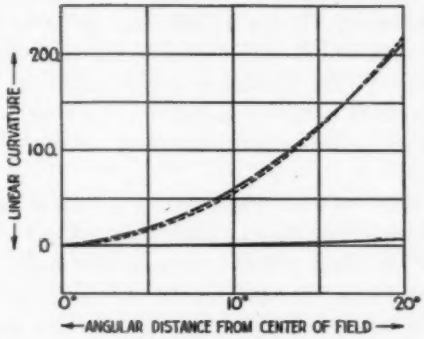

FIG. 4. *Curvature of primary image surface vs. angular distance from center of field.*

The dotted curve applies to single lens in plane of mirror. The dashed curve applies to single lens with mirror .17 f from lens. The full curve applies to the two lens system.

The ordinate is the distance from the primary (meridional) image to a plane normal to axis of system at the image of an infinitely distant axial object point. The values are in millimeters for a lens system of which the focal length is 1 meter. A positive value indicates that the image is nearer the lens system than the plane surface. The abscissa is the angular deflection of the pencil of light, i.e., twice the angle through which the mirror rotates.

The spacings and thicknesses are given in millimeters. Diameter of negative lens 44 mm. Diameter of positive lens 75 mm. Focal length of the system is 333 mm, and the radii are only approximately those obtained by direct proportion from the system of unit focal length. The curvatures of the surface have been specified in diopters in order to facilitate the construction of the system by an optician equipped with standard spectacle lens tools. Such an optician can construct the lenses on the basis of the following specifications:

One plano concave lens, power −2.50 diopters; thickness at center, 1 mm; diameter, 44 mm, and

One double convex lens, power of surface +1.25 and +3.75 dipters; thickness at center. 7 mm; diameter, 75 mm.

If it is not convenient to obtain spectacle glass in sufficiently large blanks, ordinary plate glass can be used. A system of lenses as specified above has been constructed and found to perform as desired. The improvement in the definition of the image at the edge of the field over that afforded by the more usual single lens is particularly noticeable and is of course to be expected when the comparative flatness of the primary image surface in the two cases, as indicated in Fig. 4, is noted. The most important outstanding aberration remaining to be eliminated is the lateral chromatic. Consideration was given to this and it appeared that its satisfactory elimination would necessitate the use of three components. This additional complication is considered unjustifiable, particularly when it is noted that the selective action of the photographic plate lessens the detrimental effect of the chromatic aberration.

It is evident that the case dealt with is a special one and may be generalized. The deflection may be made proportional to $a+Ma^3$ where M may be given any value within a considerable range. If $M=-1/6$, the deflection will be nearly equal to the sine of the angle of rotation of mirror and any function intermediate between the sine and tangent may be indicated by suitable design.

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TWO OCEANOGRAPHIC CURRENT-RECORDERS DESIGNED AND USED ON THE "MAUD" EXPEDITION

By H. U. Sverdrup* and O. Dahl**

The two current-recorders, which will be described here, are both propeller-instruments, recording electrically the velocity and direction of the current in the sea. The velocity of a current can easily be registered by letting the propeller operate a key which, after a certain number of revolutions of the propeller, closes or breaks an electric circuit. By using large transmission gears, the work necessary for this operation is small and does not materially influence the sensitivity of the propeller. The electric circuit is very simple because it is sufficient to bring a single, insulated cable down to the key, which naturally must be insulated from the sea-water, and the returning branch is formed by the wire on which the current-meter is suspended. In the present case the same electric circuit was utilized also for recording the direction of the currents in the sea. A recording milliammeter was used, and by means of a simple arrangement of resistances the strength of the electrical current passing through the circuit and the milliammeter was made dependent upon the direction of the current in the sea. The magnitude of the deflection of the milliammeter thus served to determine the direction of the ocean current, and the number of breaks in an hour determined the number of revolutions completed by the propeller in this time.

Of the two types which have been completed, the first is suspended in a bifilar frame and the direction of the current is referred to the plane in which this frame is oriented; the second type is suspended at the end of a single wire and the direction of the current is recorded by means of a compass-needle. The "bifilar" type is the simplest and will, therefore, be described first.

The general arrangements are shown in Fig. 1. The wires (3) and (9) which form the bifilar frame are fastened at the points (10) and (11), and are kept permanently in the vertical plane through these points by means of an 80-pound weight (1) under the bar (4) which rolls on the reels (2) when hauled up or lowered. The wires (3) and (9) serve as

* In Charge of Scientific Work.

** Aviator.

guide-lines for the current-meter (7) which, by the bronze wire (5), can be lowered to any desired depth, being loaded by the 10-pound weight (8). The cable which forms one branch of the electric circuit is marked (6).

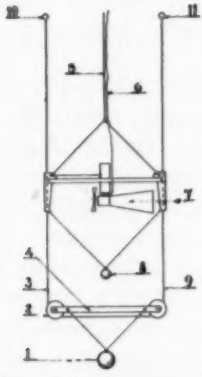

FIG. 1. *Bifilar suspension of current-recorder.*

The instrument itself hangs on ball bearings from the upper part of a tube which is closed at the top. Within this tube are placed the resistances which regulate the deflection of the milliammeter. Fig. 2 shows a schematic representation of the arrangement supposing, for

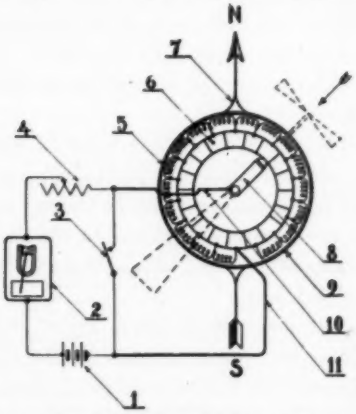

FIG. 2. *Schematic representation of electric circuit.*

the sake of simplicity, that the frame is oriented north-south. The tube is indicated by the circle (9). The ring (6) is a metal ring, which is insulated from the metal of the instrument and has been split up into

18 segments, each covering 20° of the circle. The cable (11) is connected to the segment which in the figure is to the south, and the segments are mutually connected by 17 resistances (5), but there is no connection between the segment to the south and the next segment to the east. The segments thus represent a series of resistances of which one end is connected to the cable and the other end is free. To the axis of the current-meter, which carries the propeller and the vane (both indicated in the figure), is fastened a sliding-contact (8) resting against the segment which is opposite the vane. An electric current, supplied by the battery (1) and entering the segment through the cable (11), must pass through a number of resistances until reaching the sliding-contact, whence it returns to the battery through the suspension wire (10) and the milliammeter (2). The deflection of the milliammeter, therefore, supposing the potential of the battery to be constant, must depend upon the position of the sliding-contact, which means, since this contact is rigidly connected with the vane, on the direction of the current in the sea. If this current comes from the south, the sliding-contact is resting on the segment to the south and the deflection of the milliammeter is at its maximum. If the direction of the ocean current changes clockwise from south toward west, the sliding-contact wanders from one segment to another and the deflection of the milliammeter decreases step by step according to the resistances which successively are introduced in the circuit until finally, when the vane has made a complete revolution, the deflection suddenly changes from the lowest possible value to the highest. The resistances have been so arranged that the deflection changes by even steps for every change of 20° of the direction of the current in the sea. The accuracy of the record of the direction can be increased by increasing the number of segments or replacing them by a suitably coiled circular rheostat, but 18 segments have been found to be sufficient.

The maximum deflection can be regulated by the rheostat (4), and by closing the key (3) at any time it can be ascertained whether this deflection would be reached if the sliding-contact were resting on the first segment, thus checking the potential of the battery.

By means of the arrangement which has been described here, the direction of the current in the sea would be recorded continuously with an accuracy of 20° if the electric circuit always remained closed. This is, however, not the case, for the sliding-contact is not, as supposed, connected directly to the metal of the instrument, but through a key (2) which is operated by the propeller (see Fig. 3). The latter turns a

disk provided with a small cam (5), by means of a worm gear, pitch 1:100 (3). The upper arm of the key, by means of the spring (4), is pressed against the contact plate (1) which forms a part of the sliding-contact, thus connecting this with the metal of the instrument. After 80 turns of the propeller the key is lifted from the plates by the cam (5), opening the electric circuit and closing it again when 100 turns are completed. The record of the milliammeter will thus show breaks for every 100 turns completed by the propeller.

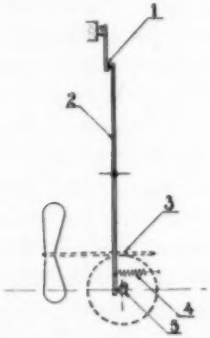

FIG. 3. *The key operated by the propeller.*

In order to avoid short-circuiting of the key by sea-water penetrating up to the plate, a cup, which is to be filled with petroleum, has been placed around the axis of the current-meter and inside of the tube. When the instrument is lowered, the air in this tube is compressed and the sea-water rises inside of it. In the absence of petroleum, the air would be absorbed by the sea-water in a day or two and the waters would rise to the contacts. The petroleum will, however, float on top of the water and prevent the absorption of the air. In shallow water the contacts will remain in air, but in greater depths they are immersed in petroleum, where they work satisfactorily.

All parts of the complete instrument are seen from the simplified drawing in Fig. 4. On the supporting frame (19) the tube (17) is mounted so that it may be turned around its own axis in order to correct for deviation from the north-south direction in the orientation of the frame. A plate (20) is fastened to this tube by a bayonet joint. On the plate is mounted the cup (6), which can be filled from the top (13) of the instrument through the rubber tube (16). Furthermore, this plate also carries the inner tube (3), which at the top carries the ball bearing (9), in which the instrument hangs, and the resistance-ring (11). The

resistance-ring is insulated from the metal of the instrument and rests on the insulating block (15) around which the resistances (10) are coiled. The cable enters through the pipe (2) and is connected to the screw (8). On the axis of the instrument, which is perforated to permit the petroleum to enter (18), are fastened the sliding-contact (12), ending in the plate (14), and the key (7). The propeller (1) runs on pivots in agate

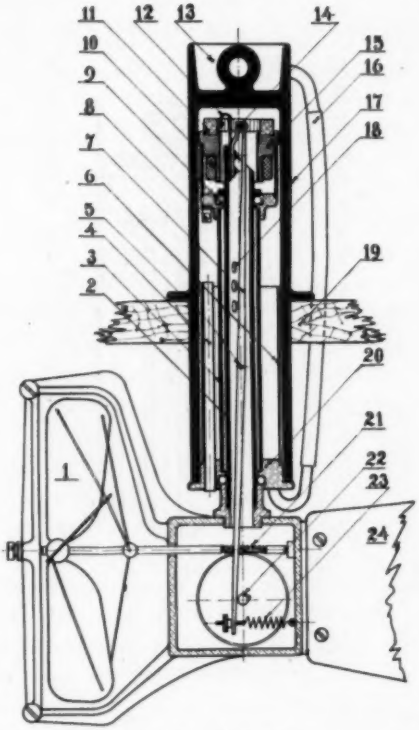

FIG. 4. *Schematic drawing of the bifilar current-recorder.*

bearings and turns the cam (22) by means of the worm gear, pitch 1:100 (21). The spring (23) presses the upper key-arm against the contact-plate. The vane is marked (24).

The second type of current-recorder registers the velocity and direction of the current in practically the same way, but the direction of the current is referred to the direction in which the compass-needle points, and not to the orientation of a fixed plane. This circumstance implies

several important modifications, which are evident from the simplified drawing of the instrument reproduced in Fig. 5.

The tube hangs at the end of a single bronze wire (15) and can be loaded to any desired weight by the lead rings (21). The plate (2) is fastened to the tube by bayonet joints. On this plate is the petroleum cup (6), which can be filled from the top of the instrument (14) through the rubber tube (3). Furthermore, this plate supports the stand (5) and (10) carrying the ball bearing (11) on which the current-meter

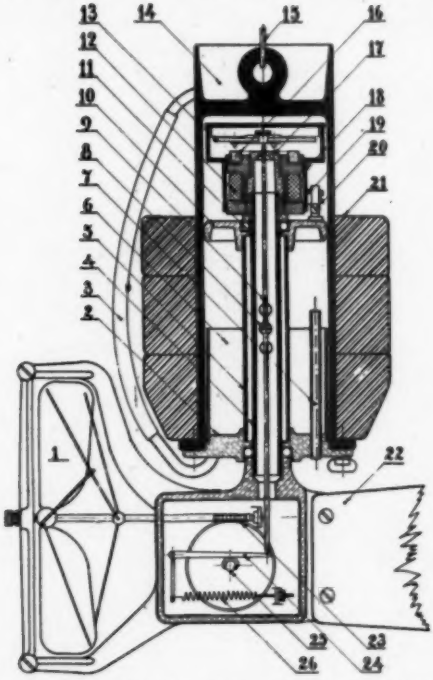

FIG. 5. *Schematic drawing of the compass current-recorder.*

hangs. The axis of the current-meter (4) is a tube which is perforated (8) to permit the petroleum to enter. It carries on top the resistance-ring (16), which thus is rigidly connected with the vane (22). The resistance-ring, as in the first model, is insulated from the metal of the instrument and split up into 18 segments connected by 17 resistances (12). The first segment in the series is connected to the ring (18). Against this ring rests the sliding-contact (19) which is fastened to the stand but insulated from the metal of the instrument. The cable is

introduced through the pipe (7) and connected to the screw (20) on the fastening of the sliding-contact. One branch of the electric circuit thus enters the resistance-ring through the sliding-contact. Inside the resistance-ring is another ring (17) which is part of the metal of the instrument and thus connected to the other branch of the electric circuit. If one of the segments in the outer ring is connected with this inner ring, the electric circuit is closed and the registering milliammeter gives a deflection corresponding to the resistances introduced in the circuit. This closing is performed by the compass-needle (13), which takes the place of the key. The compass-needle rests on a steel pivot at the end of a long pin (9) through the hollow axis of the current-meter. The lower end of this pin stands on an arm (24) resting on the cam (25) which is turned by the propeller through the worm gear (23). The propeller will thus alternately lower and raise the compass-needle. The friction between the arm (24) and the eccentric (25) can be regulated by the spring (26) which partly counterbalances the weight of the compass-needle. The latter is fastened to the upper side of a disk which, on the underside, carries three silver contacts forming a tripod, one at a distance from the pivot corresponding to the radius of the resistance-ring and two at distances corresponding to the radius of the inner ring. Only one of these two contacts is shown in the figure. During 80 revolutions of the propeller the compass-needle remains free above the rings, but at the end it is gradually lowered until it rests with one contact on the resistance-ring and two on the inner ring, thus closing the electric circuit during the next 20 turns of the propeller. The deflection of the registering milliammeter depends evidently upon the orientation of the resistance-ring relative to the compass-needle, which means, since the ring is rigidly connected with the vane, upon the direction of the current in the sea referred to the magnetic meridian. In the present instrument, the segment which is connected to the cable through the sliding-contact is placed opposite the vane and the outer contact of the compass-needle under the south end of the latter. Maximum deflection corresponds, therefore, to current from magnetic south. The resistances of the ring have been so arranged that the deflection decreases by even steps when the current changes in a clockwise direction.

The appearance of the records obtained by the two instruments is slightly different. In the first type, which we have called the "bifilar current-recorder," the electric circuit is closed during 80 revolutions of the propeller and open during 20, while in the second, which we have called the "compass current-recorder," it is open during 80 and closed

during 20 revolutions. The last-named ratio was chosen to give the compass-needle ample time for adjustment in the magnetic meridian after being lifted.

The bifilar current-meter was kept in operation in various depths during the major part of 14 months while the "Maud" was drifting with the ice on the north Siberian shelf. The bifilar frame was fastened to a stand on the ice above a hole, which had to be kept open. The orientation of the frame was never subject to sudden changes of any amount because the turning movements of the ice-field were slow. The cable was an ordinary 1 1/2 mm² okonite cable. It insulated perfectly in sea-water, and any splice could easily be insulated by rolling a thin strip of rubber tightly around it. The suspension wire was of bronze, as previously mentioned, because a steel wire deteriorates too rapidly in sea-water when connected with metal parts.

The recording milliammeter (Richard, Paris) was highly sensitive, the maximum deflection of 100 mm corresponding to only 9 milliamperes. A dry-cell battery of 4.5 volts could, therefore, supply the necessary electric energy for an indefinite period. The smallest deflection used was 12 mm, thus making a change of 20° in the direction of the current correspond to a change of 5.2 mm in the deflection of the milliammeter. The registering drum was revolving once in 24 hours, corresponding to 11 mm an hour. With this time-scale up to 40 breaks an hour could be read, corresponding to a velocity of 45 cm/sec. with the propellers used by us. This upper limit was satisfactory in our case, but could be changed by changing the pitch of the propeller. The lower limit of the currents, which still were recorded reliably, was between 4 and 5 cm/sec. This corresponds to a sensitivity somewhat smaller than the sensitivity of Ekman's propeller current-meter, which is regarded as reliable to 3 cm/sec. It is possible that the same limits can be reached with the present instrument if all movable parts were made of better materials than available to us. The constants of the propeller were determined both by direct experiment and by comparison with Ekman's current-meter.

In Fig. 6 an example of a record obtained with the bifilar current-recorder is reproduced on a reduced scale, showing a current which turns clockwise without great changes in the velocity. The numbers to the left indicate the direction from which the current comes, counting current from south as 0. The upper numbers represent the hours. To make this figure clearer, every second break in the original record has been omitted.

The compass current-recorder was completed with its use in great depths in view and also for use under conditions where a bifilar suspension would be impracticable. It was never kept in operation during any long periods, but was found to work very satisfactorily during numerous

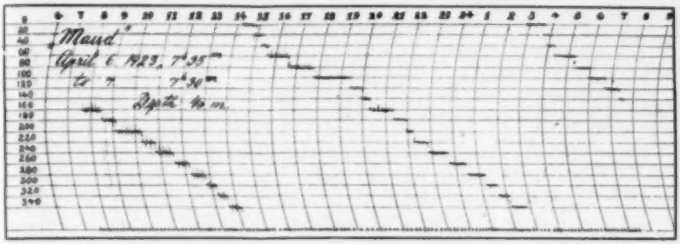

FIG. 6. *Example of record obtained by the bifilar current-recorder.*

experiments. The sensitivity of this recorder was somewhat smaller than for the other type, the weakest currents recorded being between 5 and 6 cm/sec., but this limit can probably also be reduced.

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The Reflection and Refraction of Light as a Problem of Electron Theory. P. P. Ewald. 28 pp. A Monograph of the series entitled Fortschritte der Chemie, Physik, und Physikalischen Chemie.

This is a masterly exposition of the physical processes which are supposed to occur when electromagnetic waves fall on bound electrons. Complicated mathematics is conspicuous by its absence. The author shows clearly how the spherical waves emitted by all the atoms in the medium combine to form a wave the phase of which is propagated with a velocity differing from that of light in vacuo, and also a boundary wave of velocity c which interferes completely with the incident wave and gives rise to the reflected wave. Fresnel's formulas for the intensities of reflected and refracted waves (at perpendicular incidence) are derived with extreme ease.

This subject has been placed on a firm basis only since 1912. Most of the standard (?) treatises on optics were written before that time and their treatments of dispersion are now out of date. Ewald's summary can be recommended to everyone who wishes to understand the present state of our knowledge, without entering into tiresome details.

Quantum theories of dispersion are mentioned but not discussed. Whatever the nature of our final views, the electron theory of dispersion will always be a useful tool and a splendid example of the power of electromagnetic theory.

ARTHUR EDWARD RUARK

Statistical Equilibrium between Neutral Atoms, Ionized Atoms and Detached Electrons.—It is assumed (*a*) that when a neutral atom of ionization potential hv_0/e is struck by a quantum of frequency ν/ν_0, an electron of speed v given by $h(\nu-\nu_0)=\frac{1}{2}mv^2$ is liberated; (*b*) that when an electron of speed v passes within a distance less than s from an ionized atom, it is captured; (*c*) that the effective cross-section of a quantum, so far as collisions with atoms are concerned, is proportional to λ^2; (*d*) that the velocities of the free electrons are distributed according to Maxwell's law; (*e*) that the frequencies of the quanta are distributed according to Wien's law. Equating for each dv the rates of the two processes described by (*a*) and (*b*), with use of the hypotheses (*c*), (*d*) and (*e*), Ornstein concludes that the chance that a collision between a quantum and an atom will lead to ionization is proportional to $(\nu-\nu_0)$ if the electrons are not attracted by the ionized atoms up to the instant of reaching the critical distance s, and proportional to $(\nu-\nu_0)\,[s+e^2/h(\nu-\nu_0)]$ if they are attracted according to the inverse-square law. These conclusions might be tested by examining the bands lying beyond the convergence-frequencies of series in line absorption spectra. Ornstein's application of these ideas to the "classical" theory of metallic conduction leaves the principal difficulties unabated.—[L. S. Ornstein, Utrecht; ZS. f. Phys. *32*, pp. 673-677; 1925].

KARL K. DARROW

Energy-losses suffered by fast electrons traversing thin laminae of Al and Ni.—The method resembles the familiar scheme of Rutherford and Robinson, de Broglie, and others; the beam of electrons from a hot filament, accelerated through a P.D. of 4000 to 13000 volts and sent then through narrow slits alternately covered and uncovered by the metal under investigation, is finally swung around by a magnetic field against a photographic plate. Considerable troubles were encountered with so adjusting the slits as to get sharply-defined beams, with avoiding oscillations in the high-voltage circuits, and with making the proper allowances for the dependence of the blackening of the plate (Schumann plates had to be used) upon electron-speed and total number of incident electrons. Not all the emergent electrons have the same speed, there being a distribution-in-speed about a most-probable value discretely less than the original speed; the higher the original speed the more nearly do the emergent electrons cluster about the most-probable velocity. Data obtained by piling up 0.5μ sheets of Al and 0.05μ sheets of Ni agree with Thomson's formula $V_0^4-V_m^4=ad$ for the relation among original speed V_0, most probable emergent speed V_m and thickness d; the values given for a are $6.4\cdot10^{21}$ for Al and 19.10^{21} for Ni.—[O. Klemperer (Würzburg); ZS., f. Phys., *34*, pp. 532–44; 1925.]

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